



# **Closing Global Atmospheric Water Vapor and Heat Budgets with Remote-Sensing and Reanalysis Data**

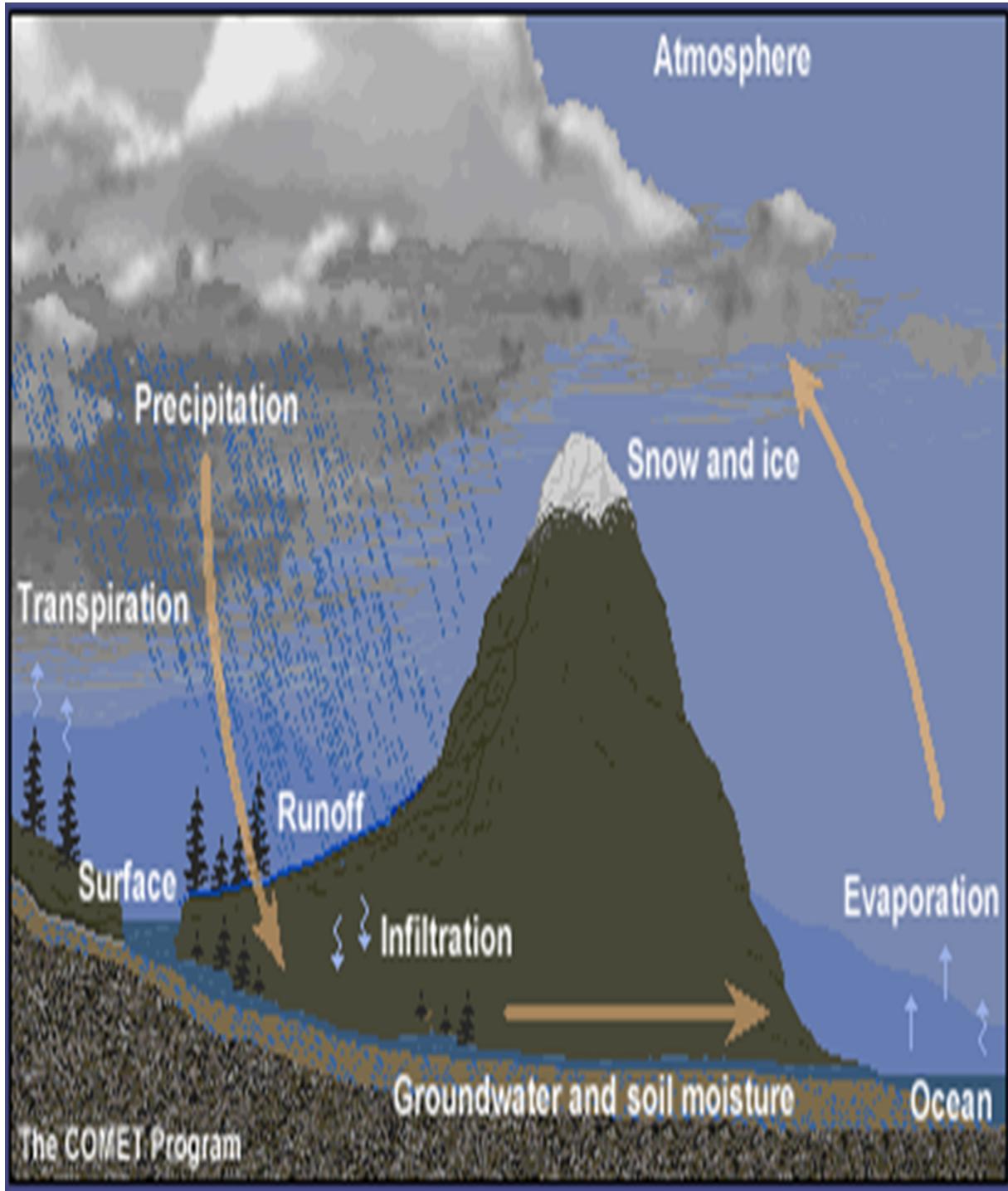
Sun Wong, Jet Propulsion Laboratory, California Institute of Technology

Collaborators: Eric Fetzer, Brian Kahn, Baijun Tian, William Olson, Tristan L'Ecuyer, Ju-Mee Ryoo, Bjorn Lambrightsen

(March 1<sup>st</sup>, 2011, Yuk Yung's Seminar: Caltech.)

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**Precipitation:**

TRMM, GPCP,...

MERRA, ECMWF,...

**Surface evaporation:**

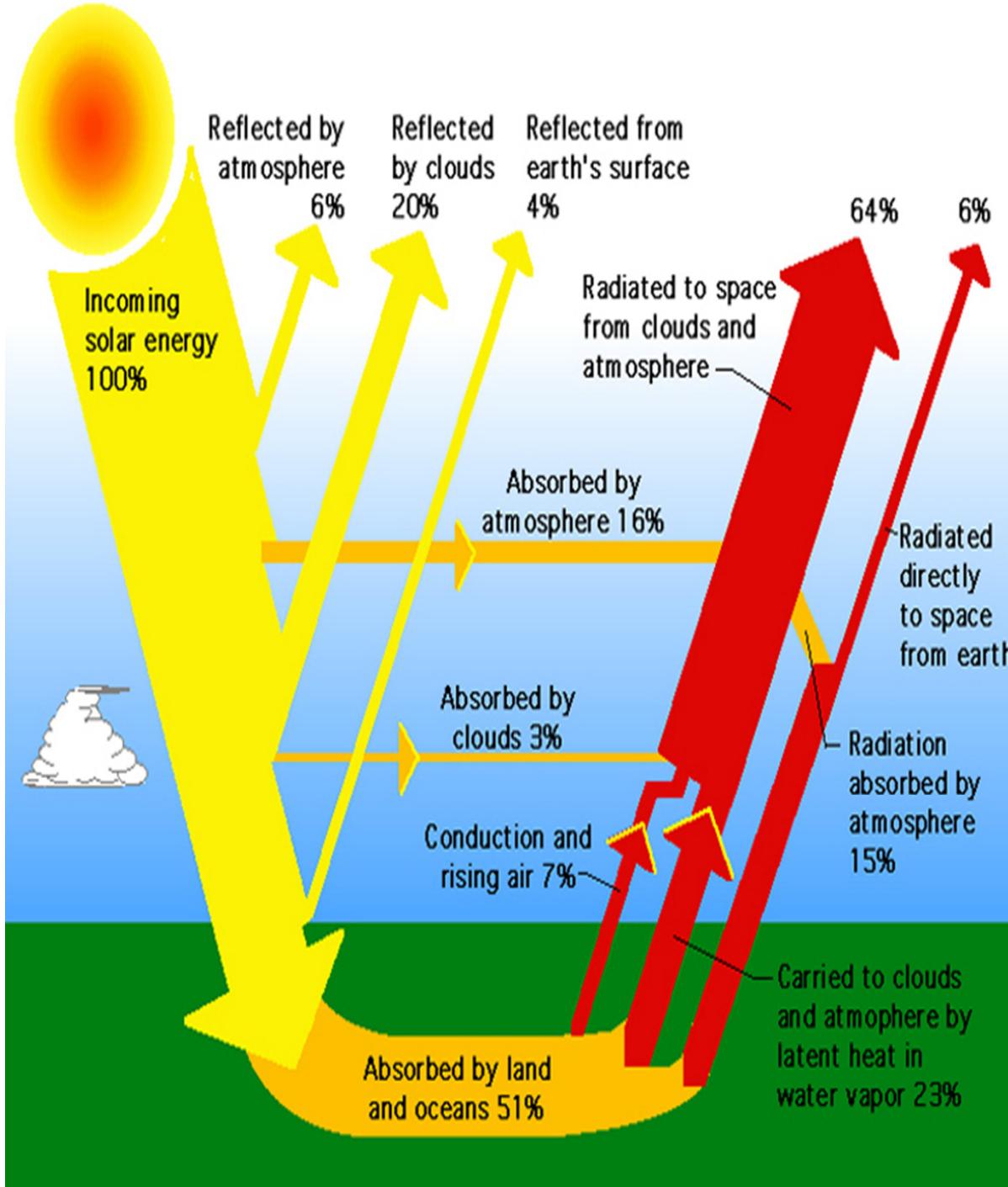
GSSTF2b, OAFlux, ...

MERRA, ECMWF....

**Atmospheric water:**

AIRS, IASI q retrievals,

MERRA, ECMWF



## Radiative Heating:

Tristan L'Ecuyer  
(TRMM, CloudSat,...)  
MERRA, ECMWF,...

## Latent Heating:

William Olson  
(TRMM)  
Shoichi Shige (TRMM)  
MERRA, ECMWF,...

## Temperature:

AIRS, IASI T retrievals  
MERRA, ECMWF,...

## Questions to Ask

- Are these independent estimates of components of hydrological cycle physically consistent with each others?
- Are these independent estimates of components of energy cycle physically consistent with each others?

## Local Balance for Hydrological Cycle (Yanai et al., 1973)

$$\begin{aligned} S &= -(\partial[q]/\partial t + [u] \cdot \partial[q]/\partial x + [v] \cdot \partial[q]/\partial y + [\omega] \cdot \partial[q]/\partial p) \\ &= C - E + \partial[\omega'q']/\partial p \end{aligned}$$

q: AIRS specific humidity (g/kg)

x, y, p: longitude, latitude, pressure coordinates

[ ] : averaged over a  $10^\circ \times 5^\circ$  grid

u, v,  $\omega$ : winds from GEOS5 MERRA

E, C,  $-\partial[\omega'q']/\partial p$ : Evaporation, Condensation, eddy term

S : In literature, it's related to Q2

$$\begin{aligned} \int S \cdot dp/g &= \int (C - E + \partial[\omega'q']/\partial p) \cdot dp/g \\ &\approx \text{Precipitation} - \text{Surface Evaporation} \end{aligned}$$

## **Local Balance for Hydrological Cycle**

$$\int S \cdot dp/g \approx \text{Precipitation} - \text{Surface Evaporation}$$

S : AIRS q profiles and MERRA or other reanalysis winds

Precipitation: TRMM 3B42 (Huffman, 2007)

Surface Evaporation: GSSTF2b (Shie et al., 2009; Chou et al., 2003)

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## **Local Balance for Atmospheric Energy Cycle**

$$\frac{\partial[T]}{\partial t} + [u] \cdot \frac{\partial[T]}{\partial x} + [v] \cdot \frac{\partial[T]}{\partial y} + [\omega] \cdot \frac{\partial[T]}{\partial p} - \kappa \omega T / p = Q_1 \text{ (diabatic heating)}$$

L. H. S.: AIRS T retrievals, and MERRA winds

R. H. S.: TRAIN Q1 (L'Ecuyer and Stephens, 2007; Grecu and Olson, 2006)

# What to Test?

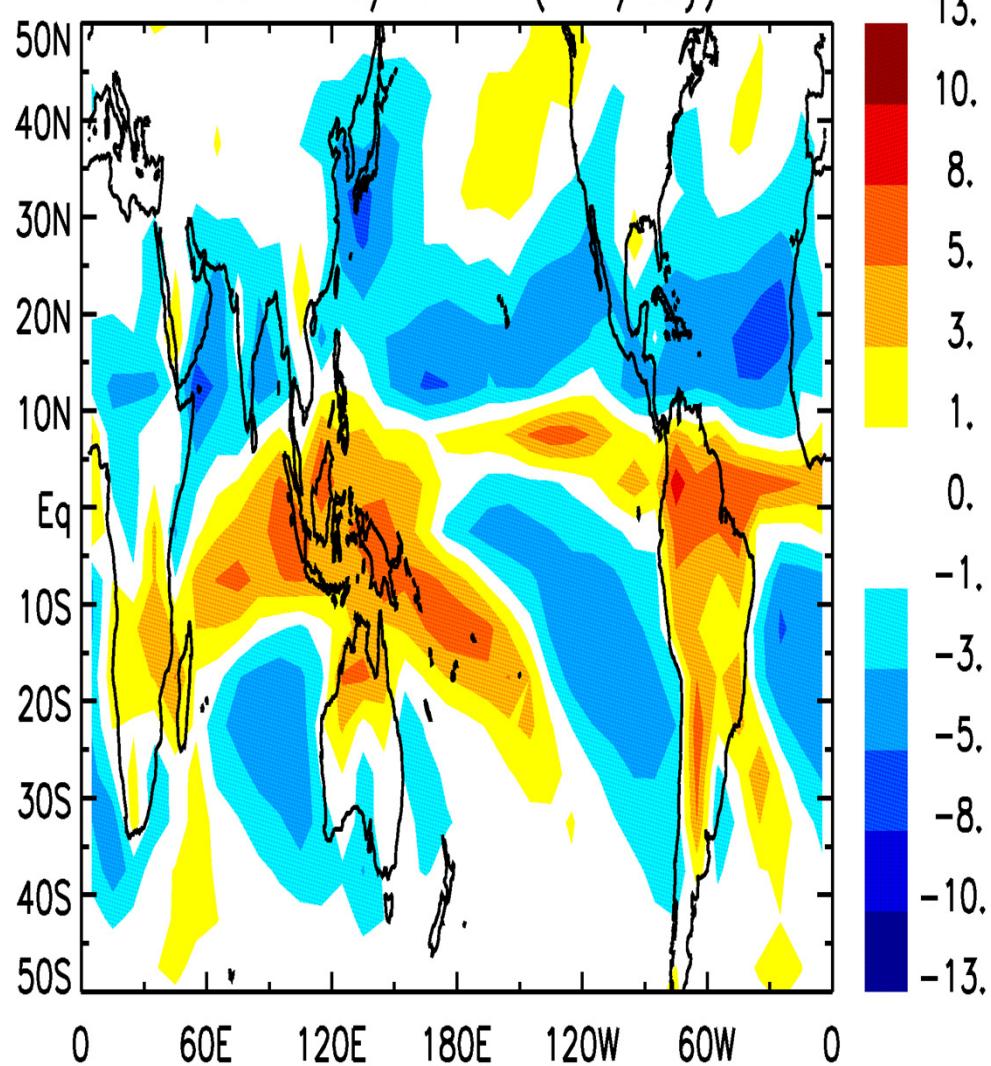
- Seasonal Climatologies of hydrological cycle (J. Climate under review)
- All-time scale variability of P–E (J. Climate under review)
  - Processes:  
Indian Monsoon (Wong et al., 2011, J. Climate)  
Atmospheric Rivers (on-going research)

Sun.Wong@jpl.nasa.gov

# Seasonal Climatologies of $\int Sdp/g$ (AIRS q + MERRA winds)

Winter 2004-2008

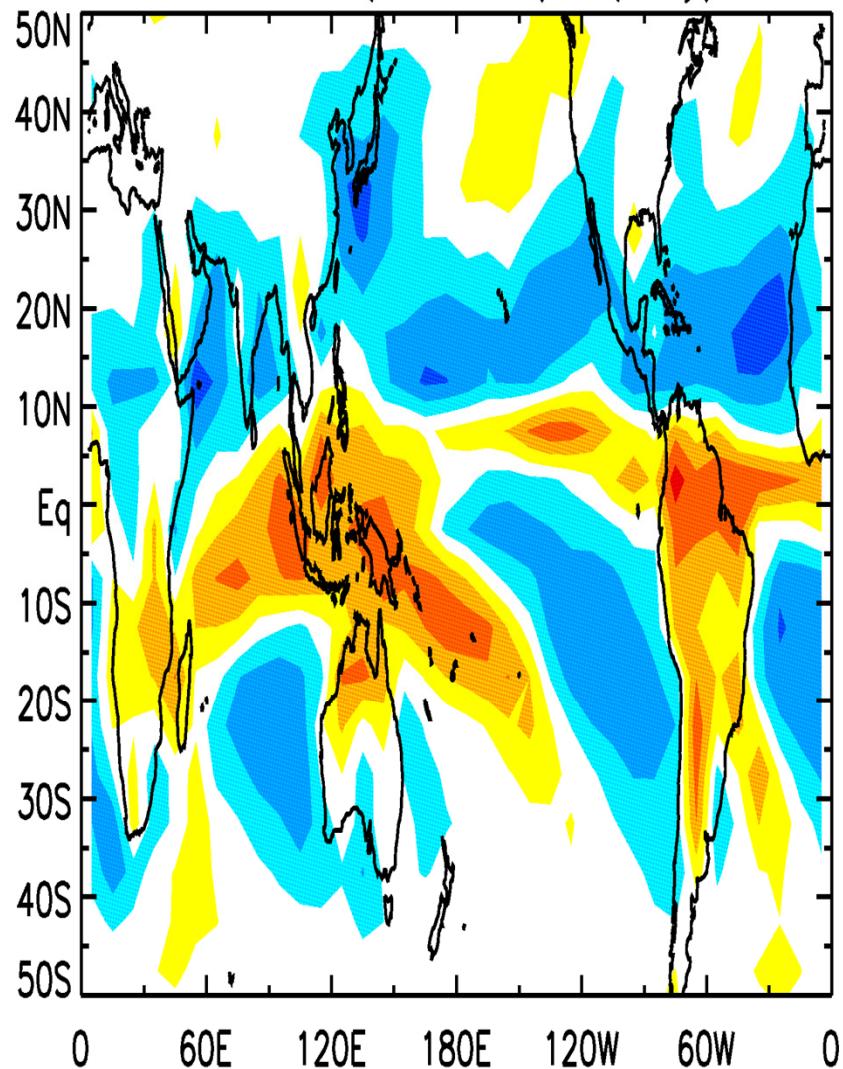
DJF AIRS/MERRA (mm/day)



# Seasonal Climatologies of $\int Sdp/g$ (AIRS q + MERRA winds)

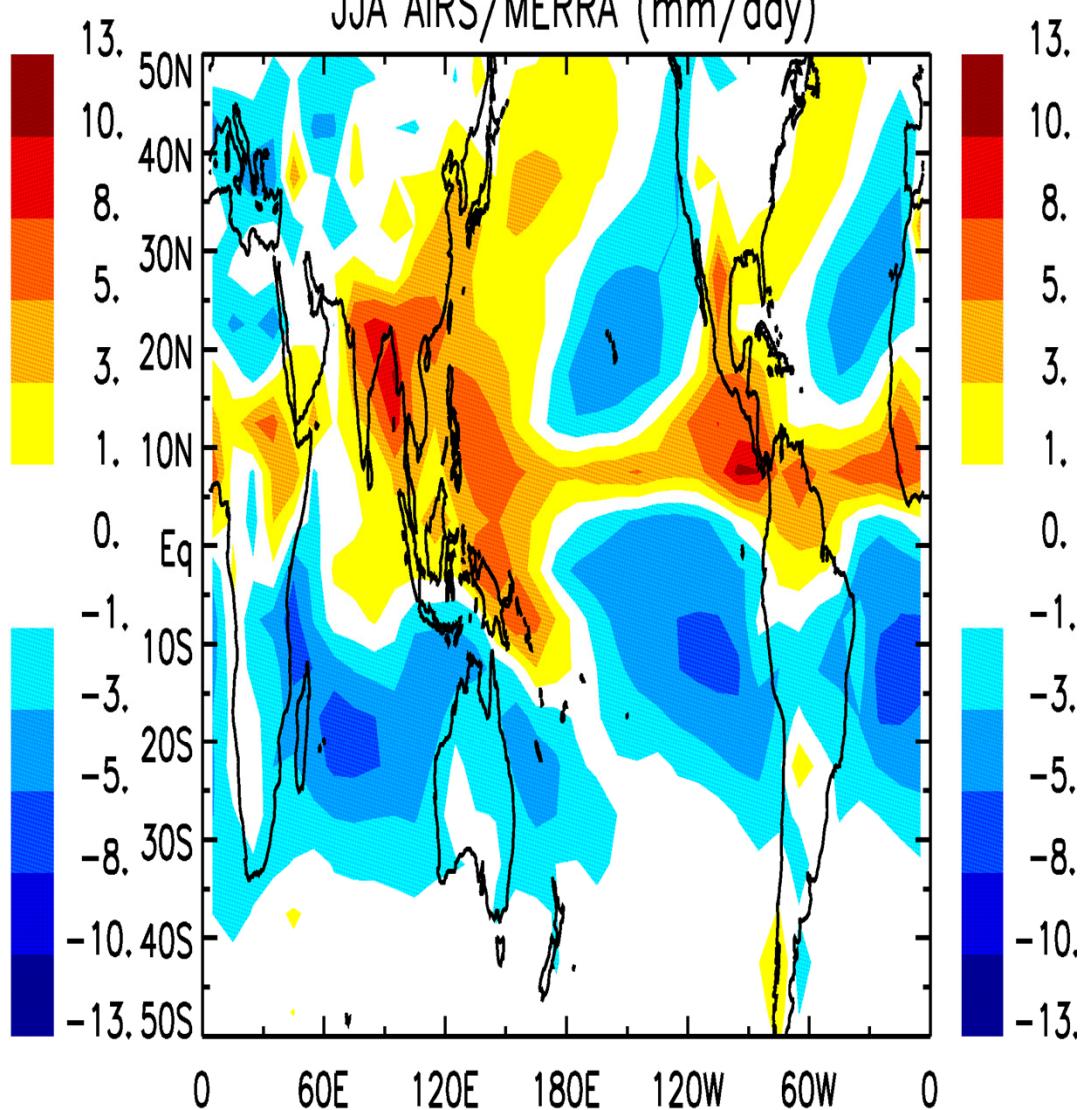
Winter 2004-2008

DJF AIRS/MERRA (mm/day)



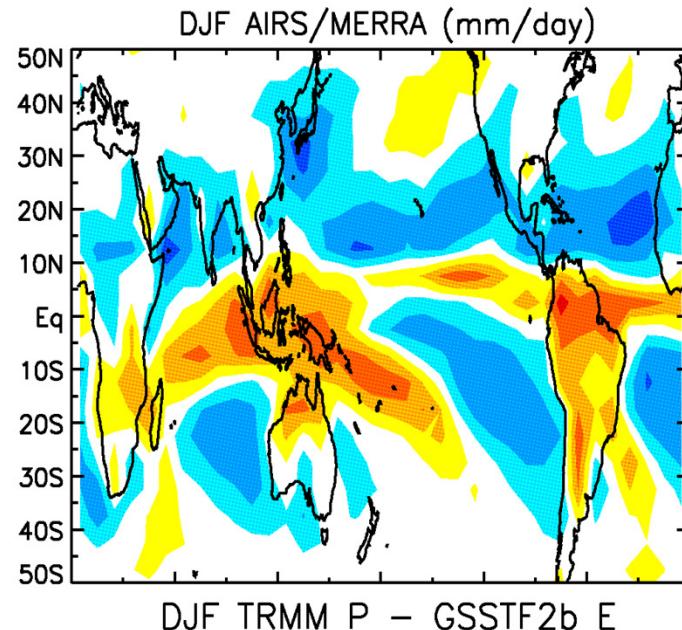
Summer 2004-2008

JJA AIRS/MERRA (mm/day)

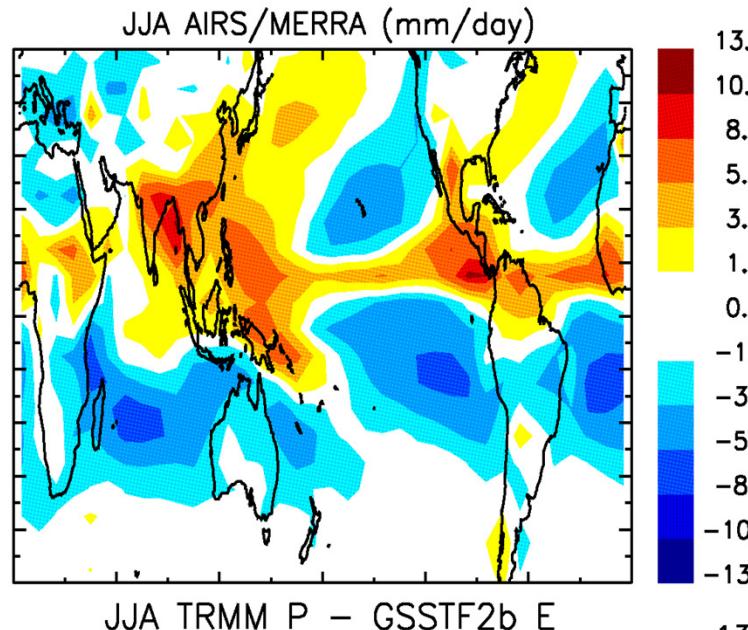


# Comparison of $\int Sdp/g$ with P-E

Winter 2004-2008



Summer 2004-2008



$\int Sdp/g$

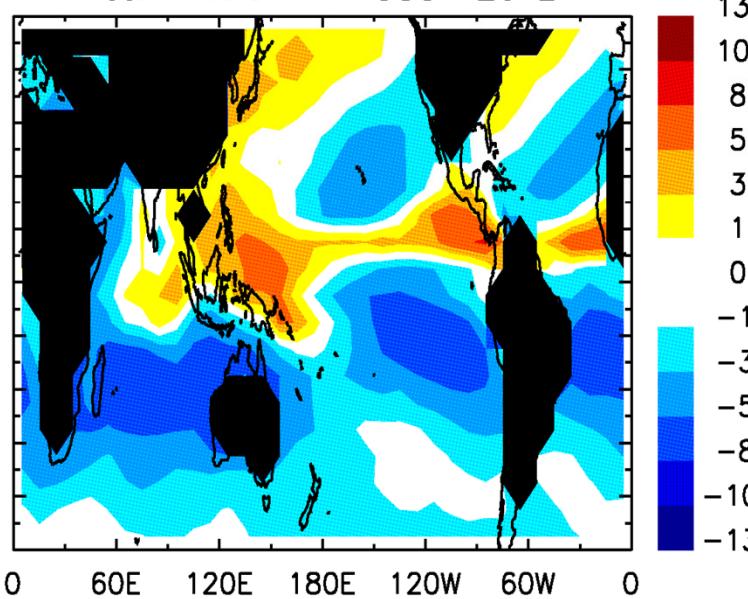
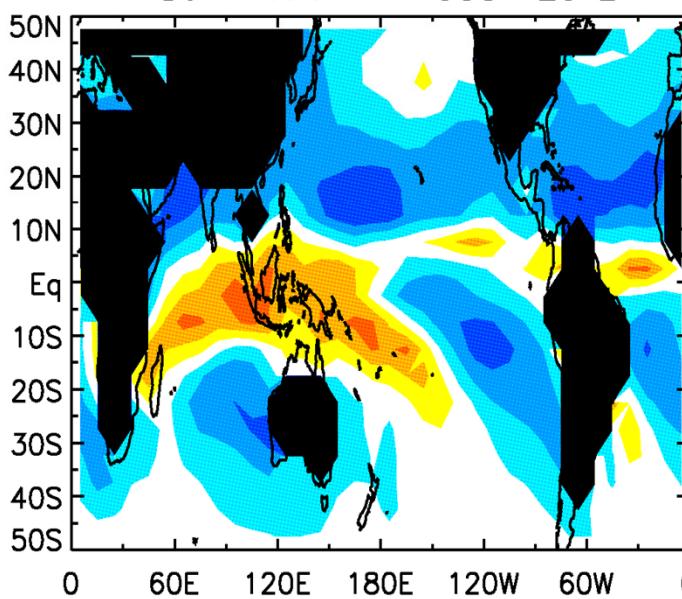
AIRS q

MERRA winds

P-E

P: TRMM  
3B412

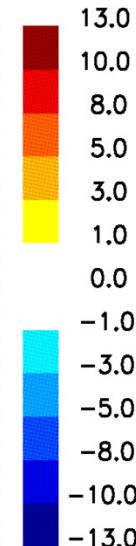
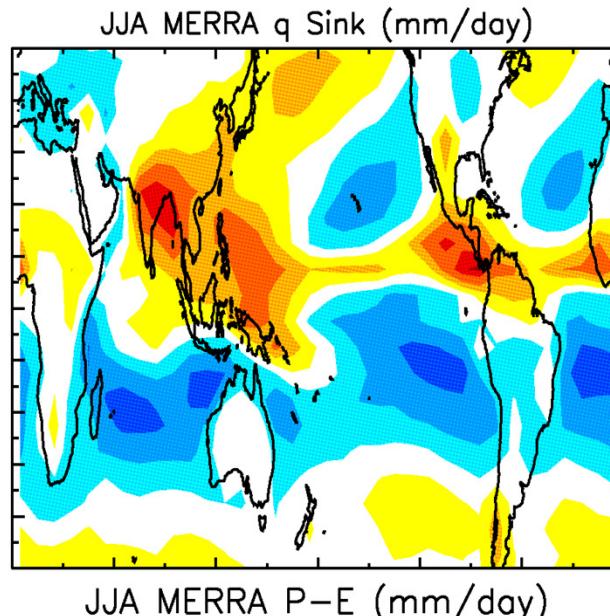
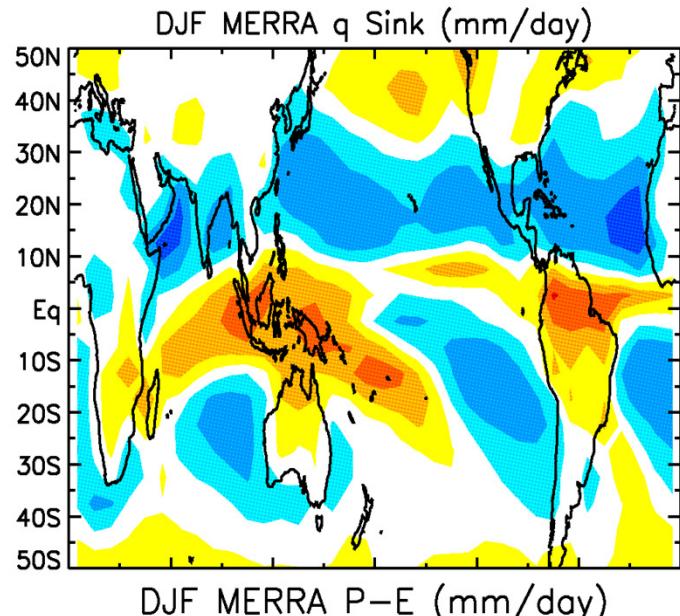
E: GSSTF2b



# Comparison of $\int Sdp/g$ with P-E for the MERRA

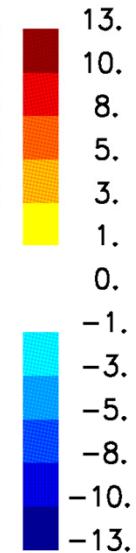
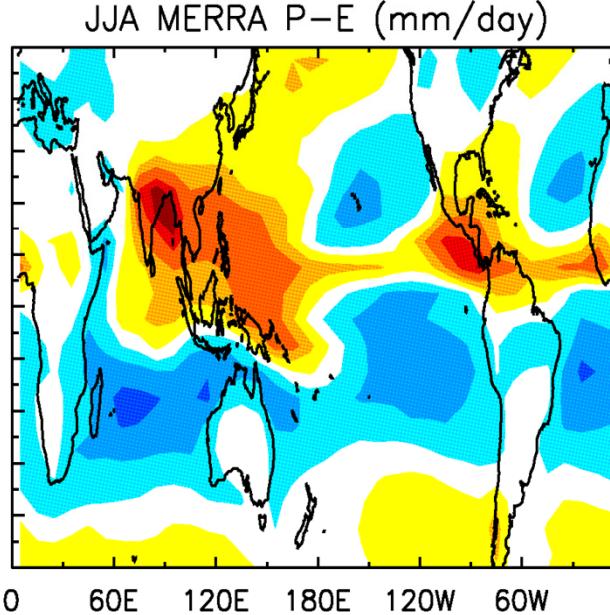
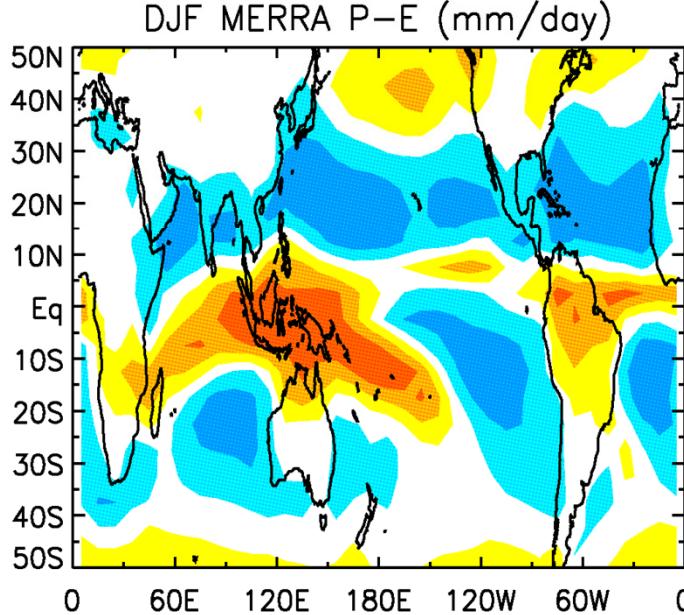
Winter 2004-2008

Summer 2004-2008



$\int Sdp/g$

MERRA q  
budget

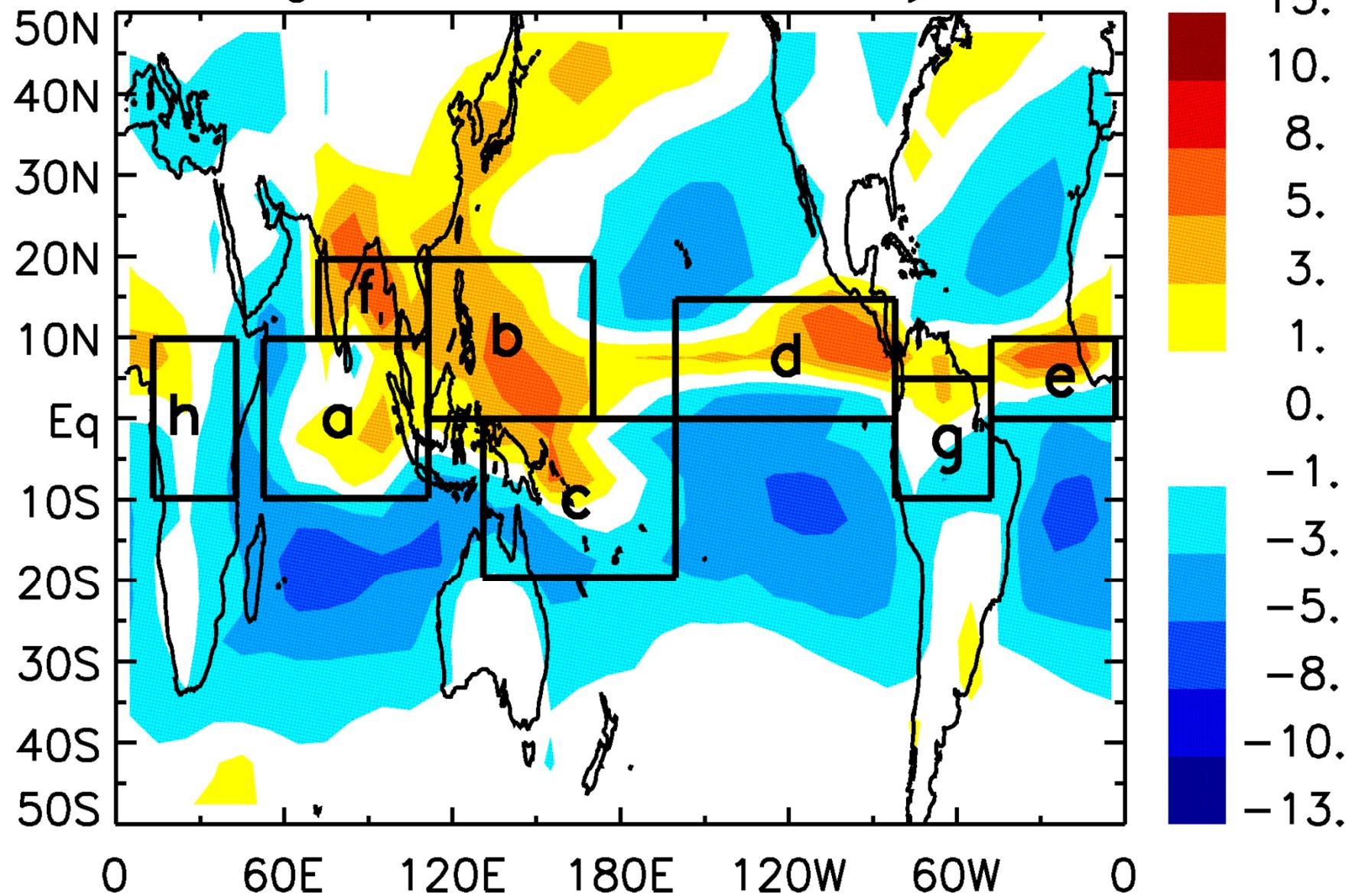


P-E

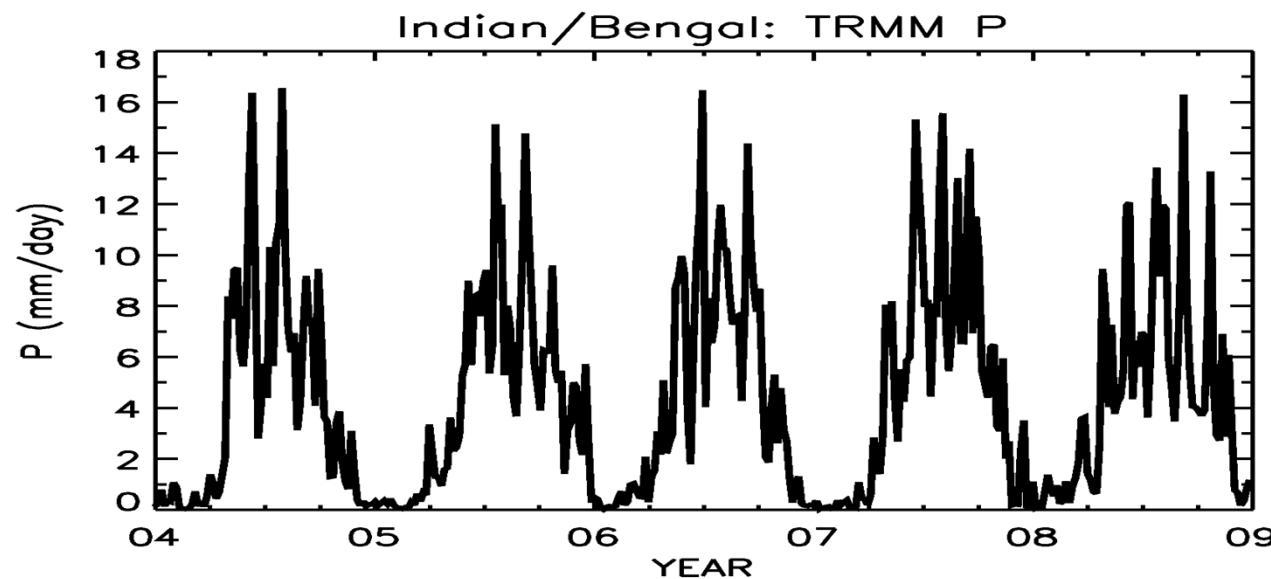
MERRA P  
and E  
modules

# All Time-Scale Variability

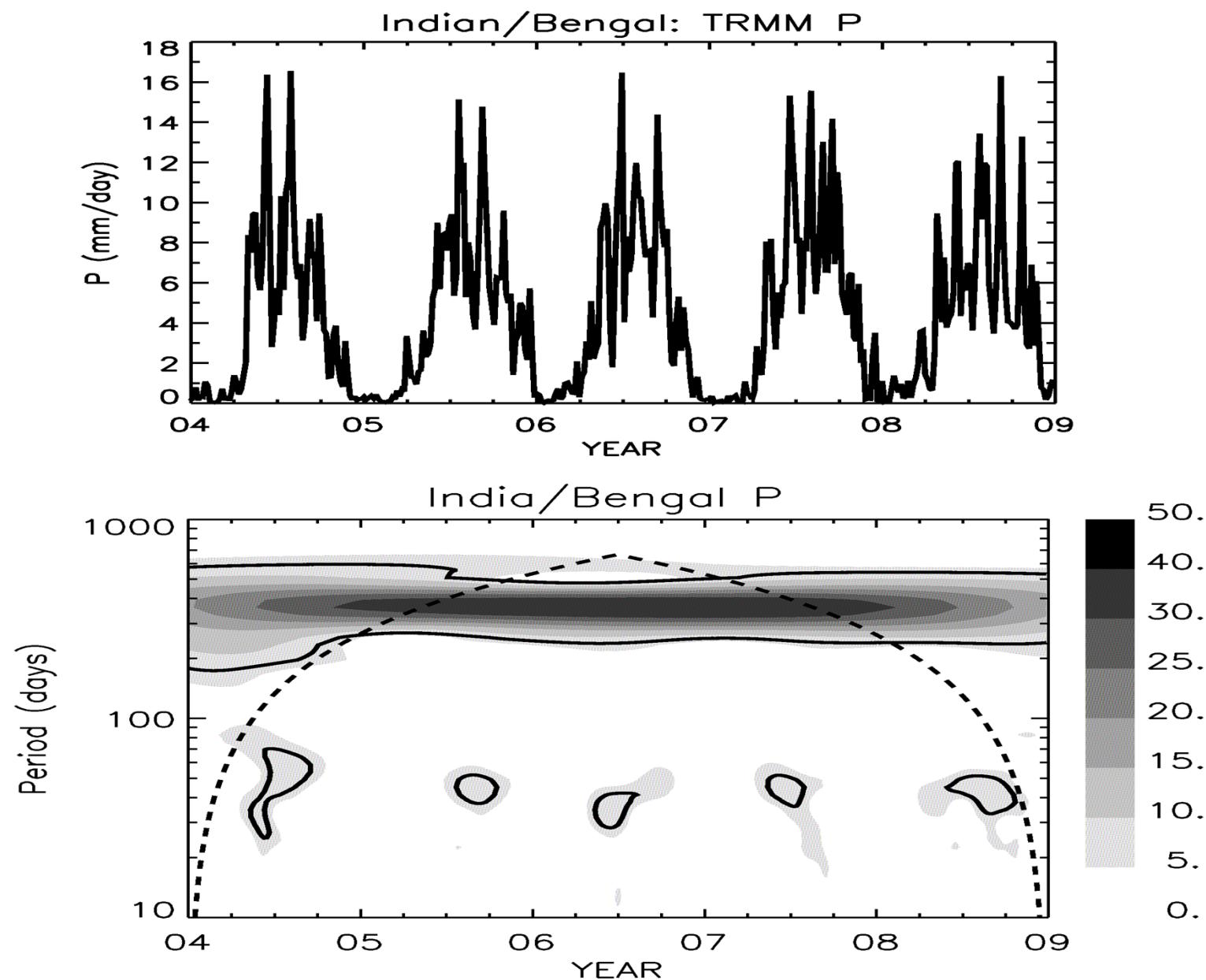
## Regions for Wavelet Analyses

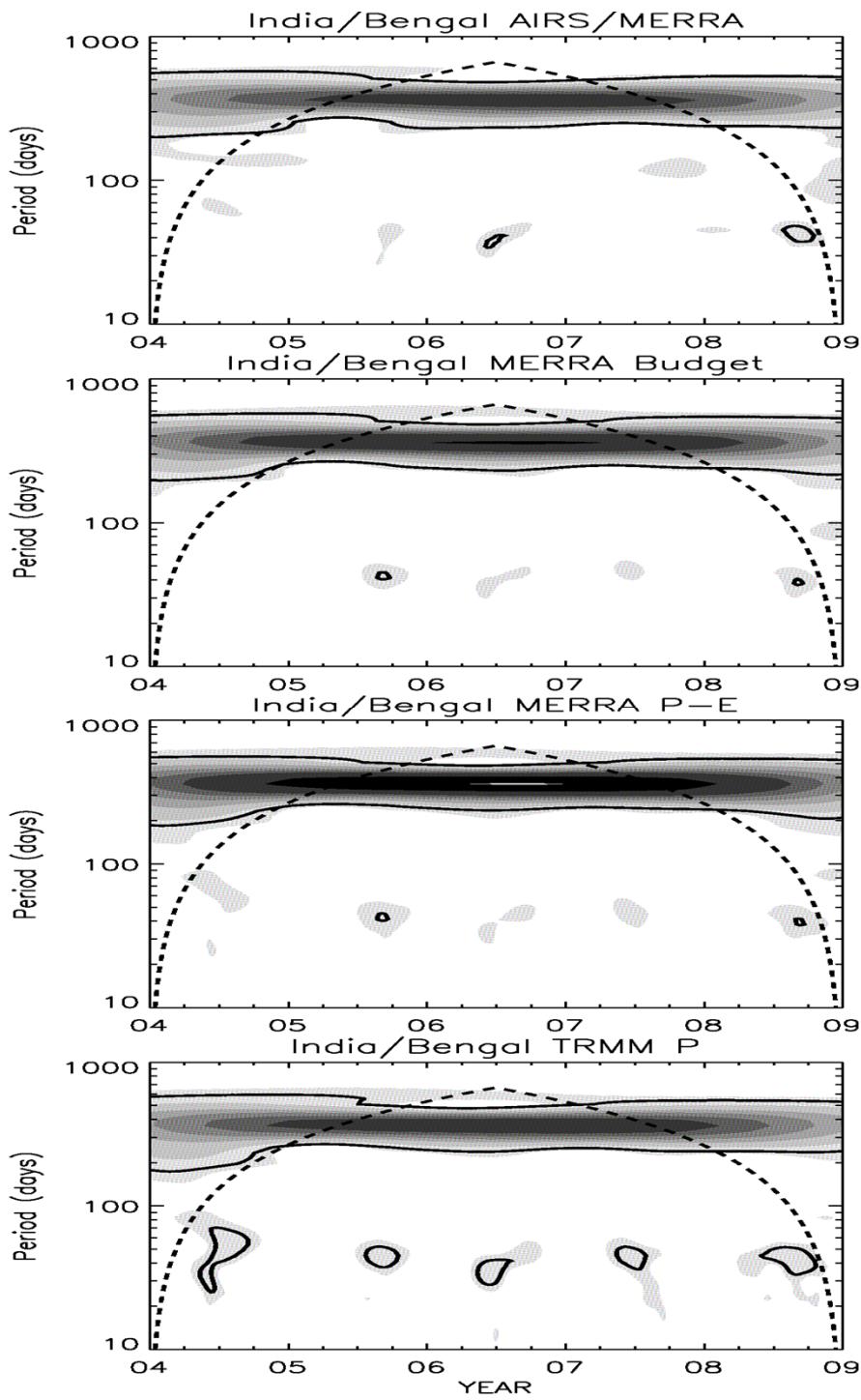


# Indian Continent and Bay of Bengal Precipitation



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$\int Sdp/g$  AIRS q and MERRA winds

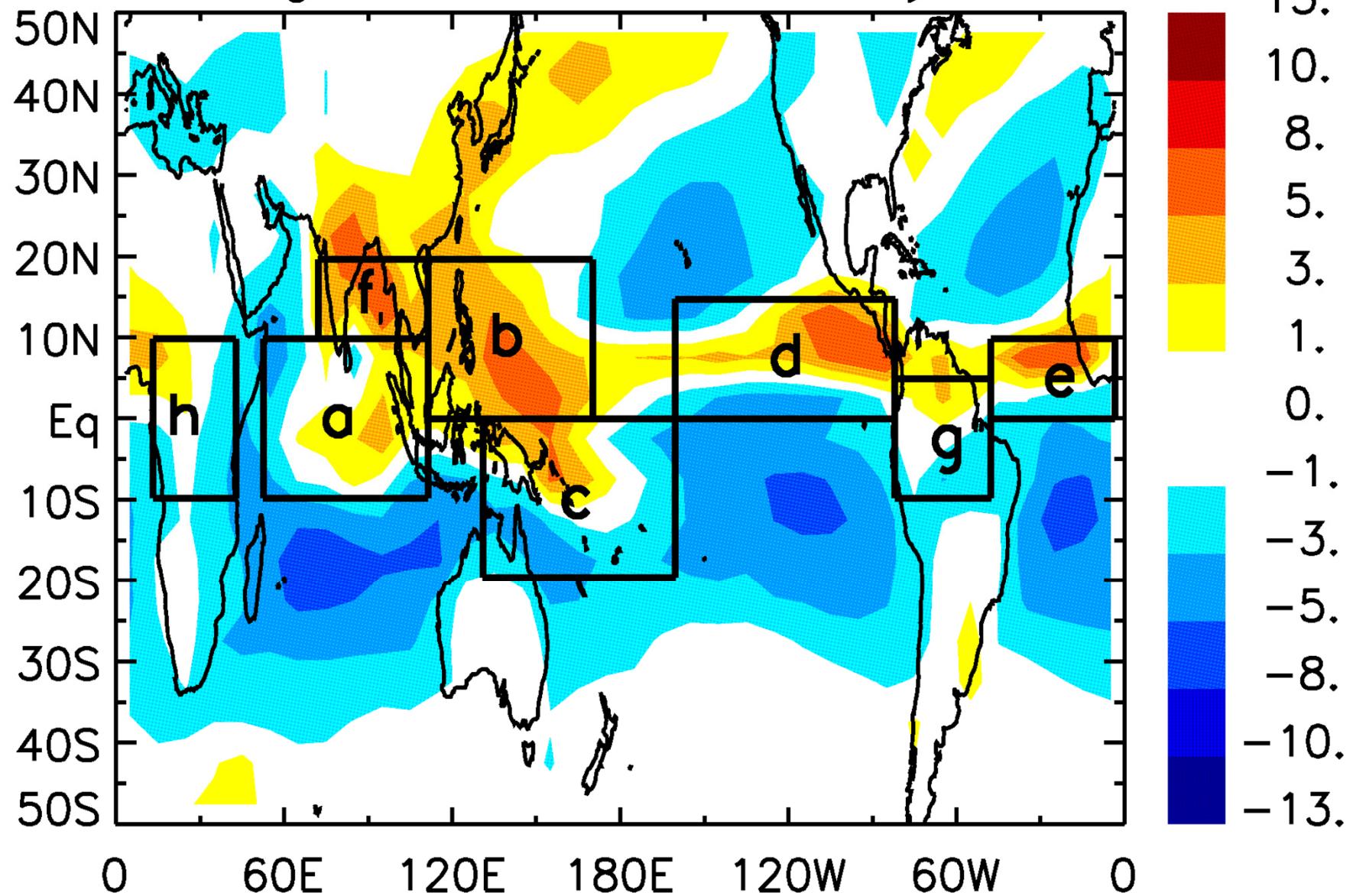
$\int Sdp/g$  MERRA q budget

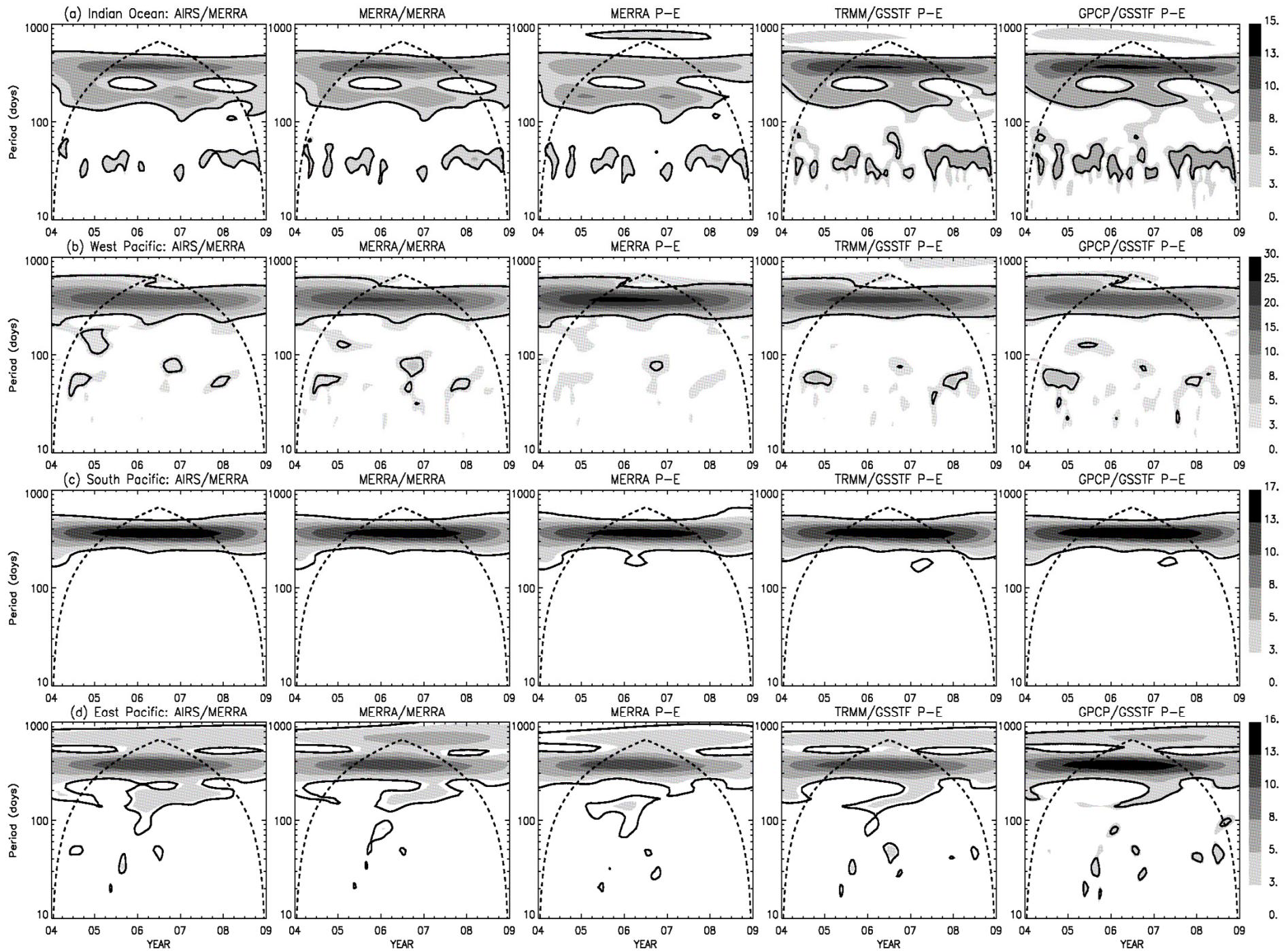
MERRA P-E

TRMM 3B42 P

# All Time-Scale Variability

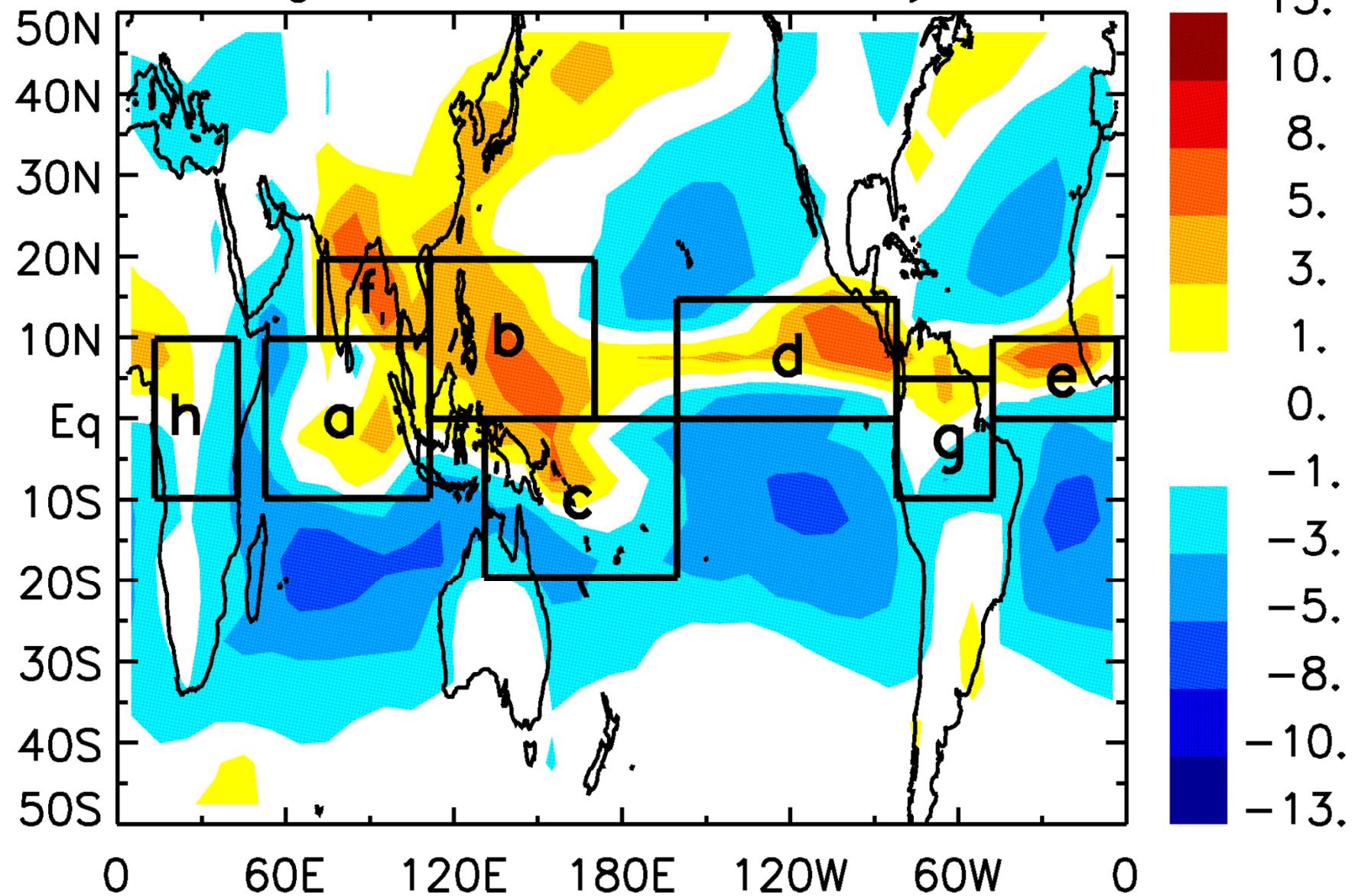
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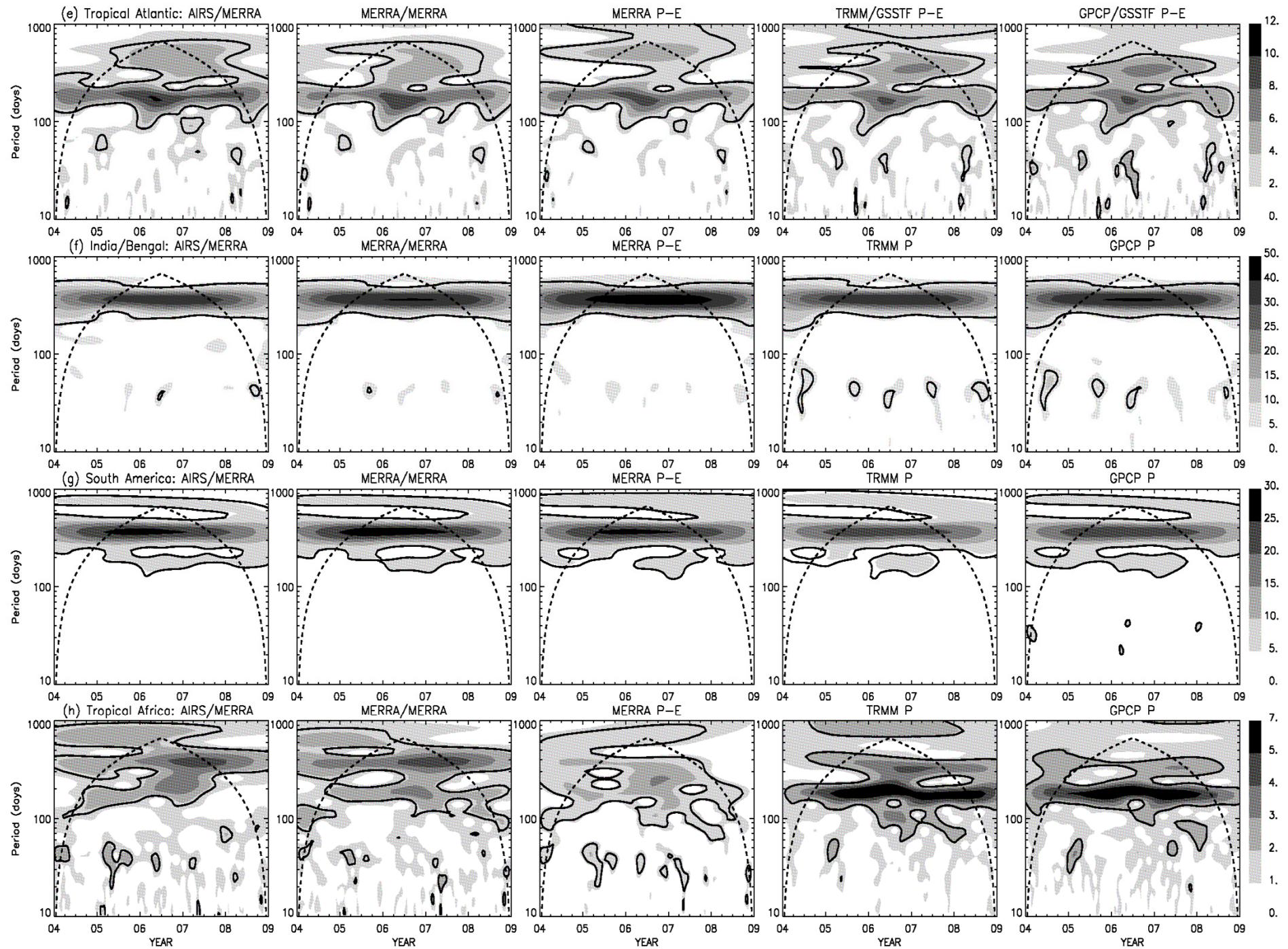




# All Time-Scale Variability

## Regions for Wavelet Analyses



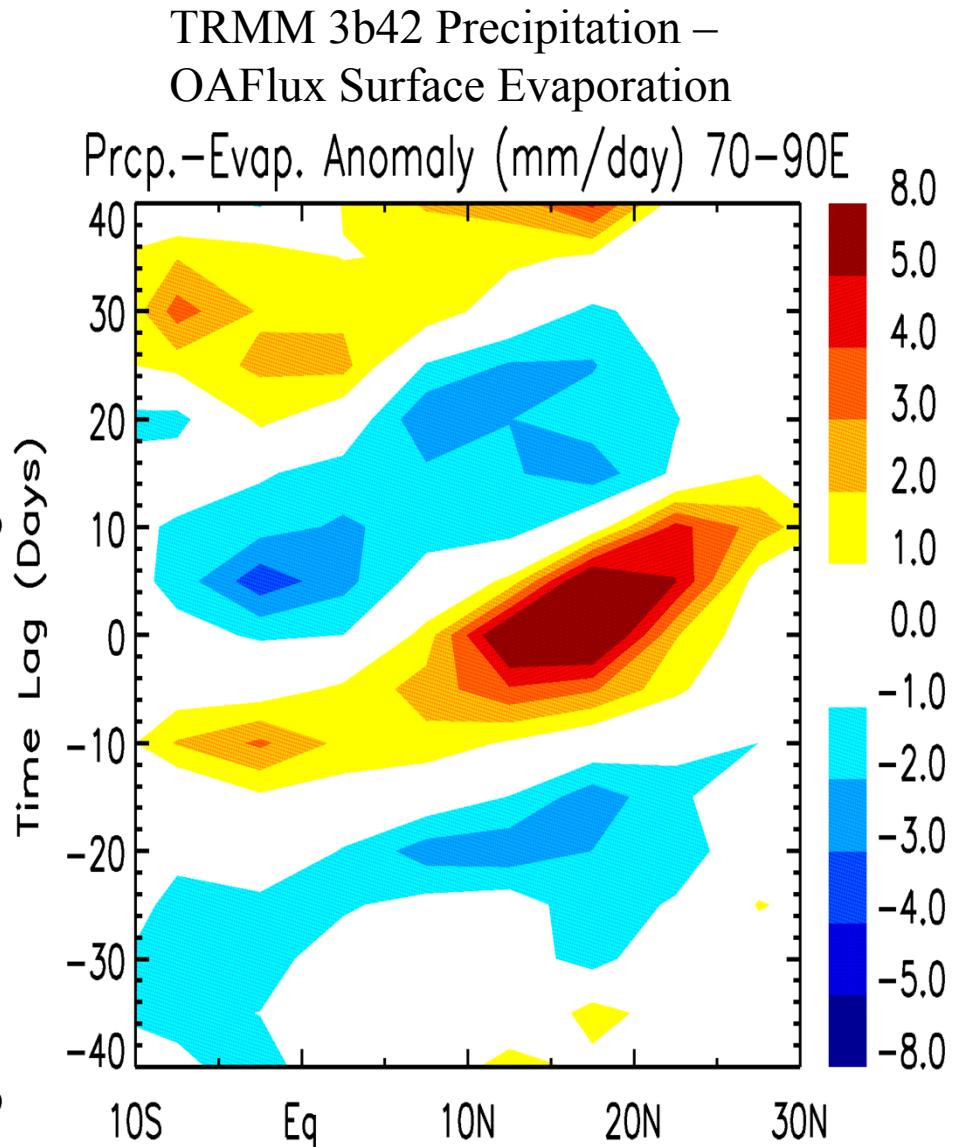
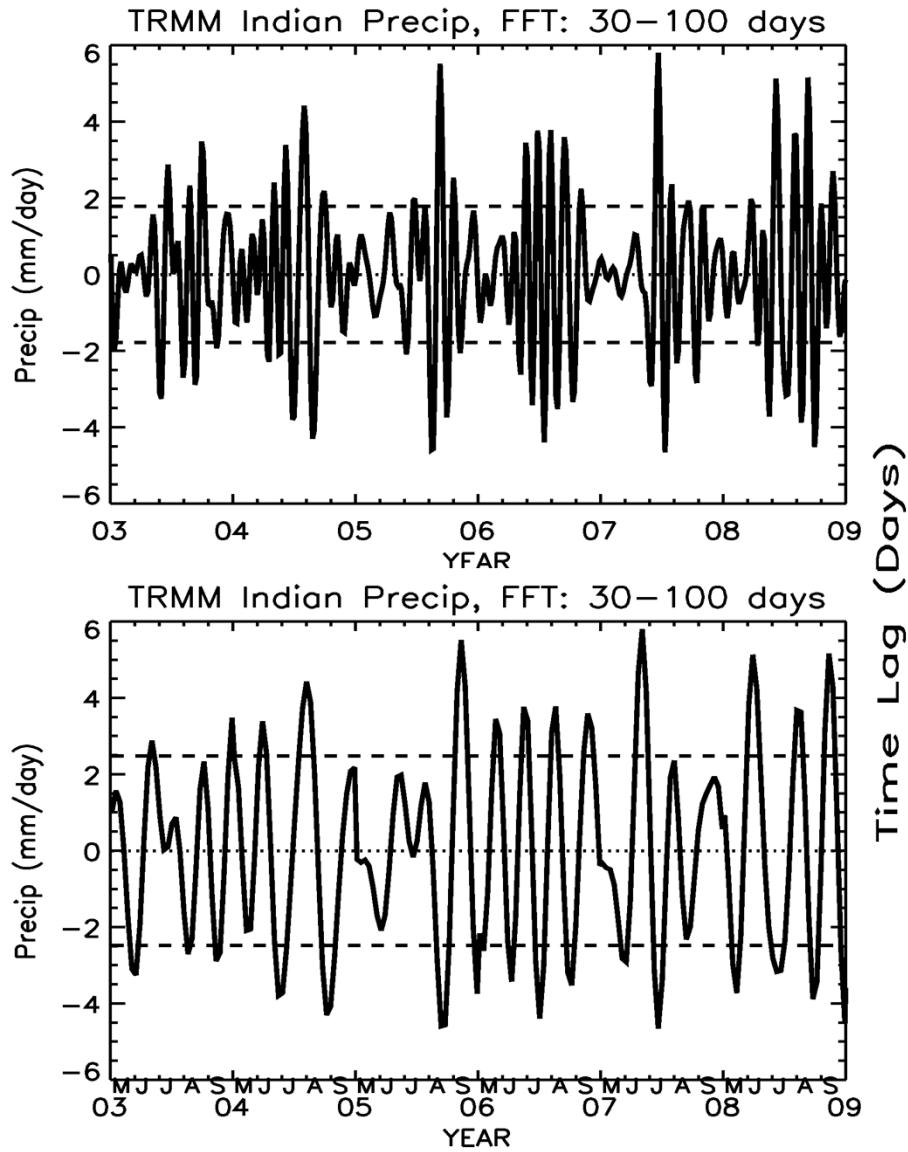


## What to Test?

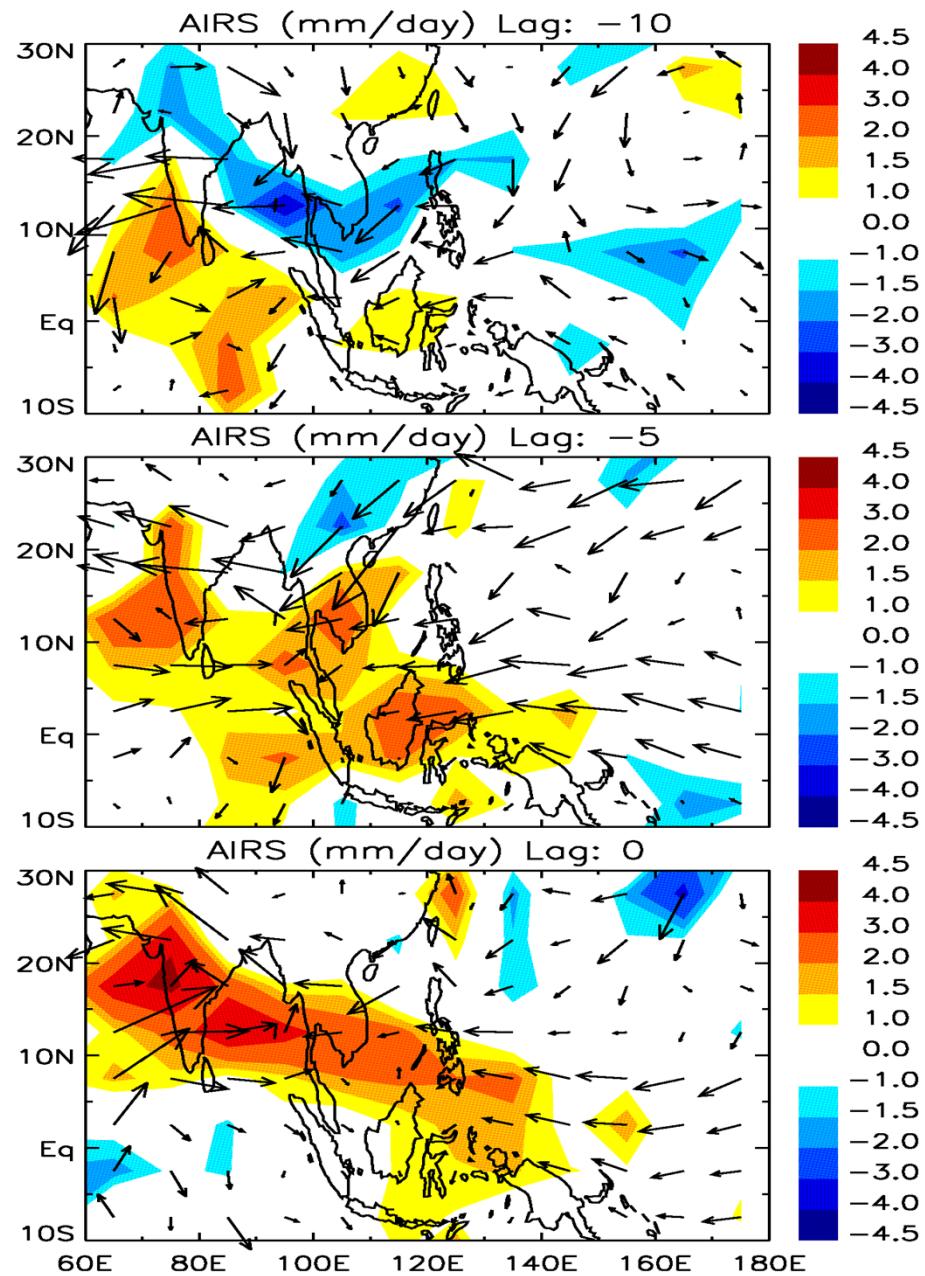
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  - Processes:  
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Atmospheric Rivers (on-going research)

# FFT Filter of Indian Precipitation 30-100 days

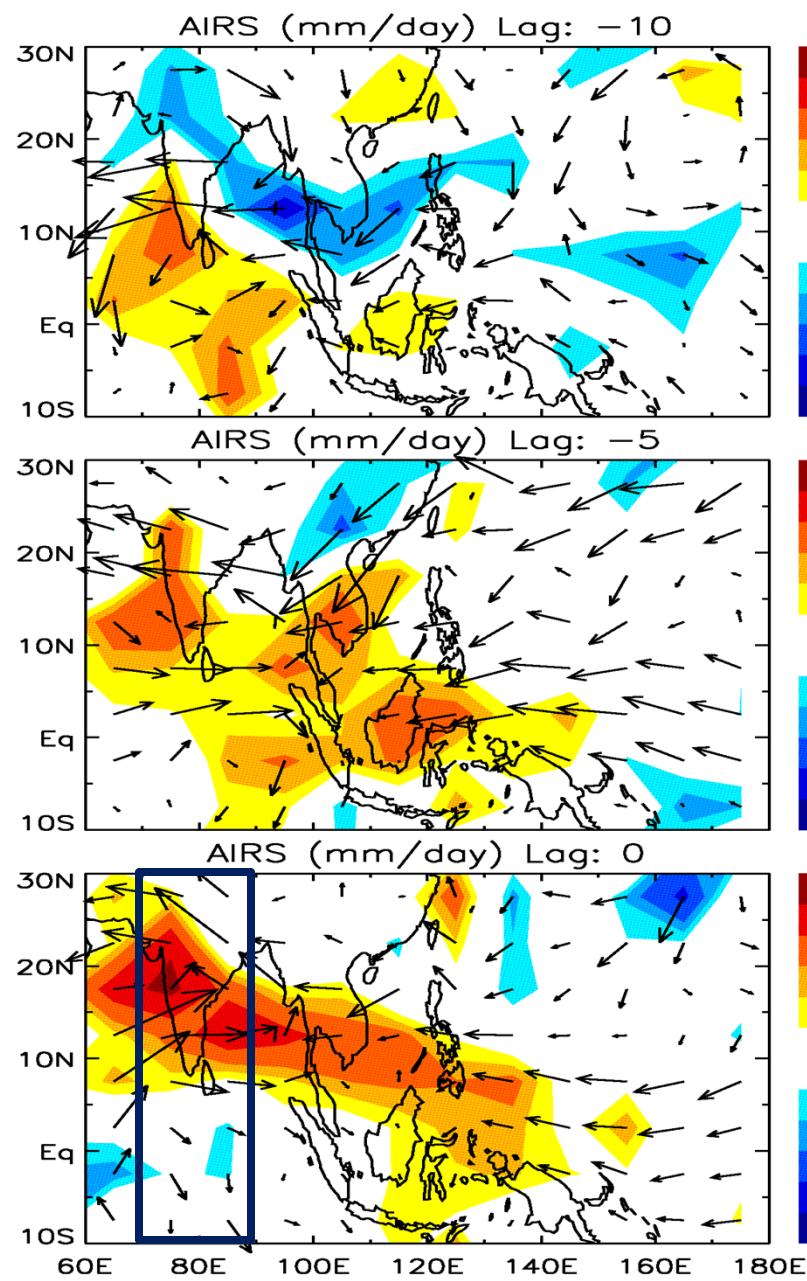
## Hovmöller Diagram of Time Lag Composite of Anomalies



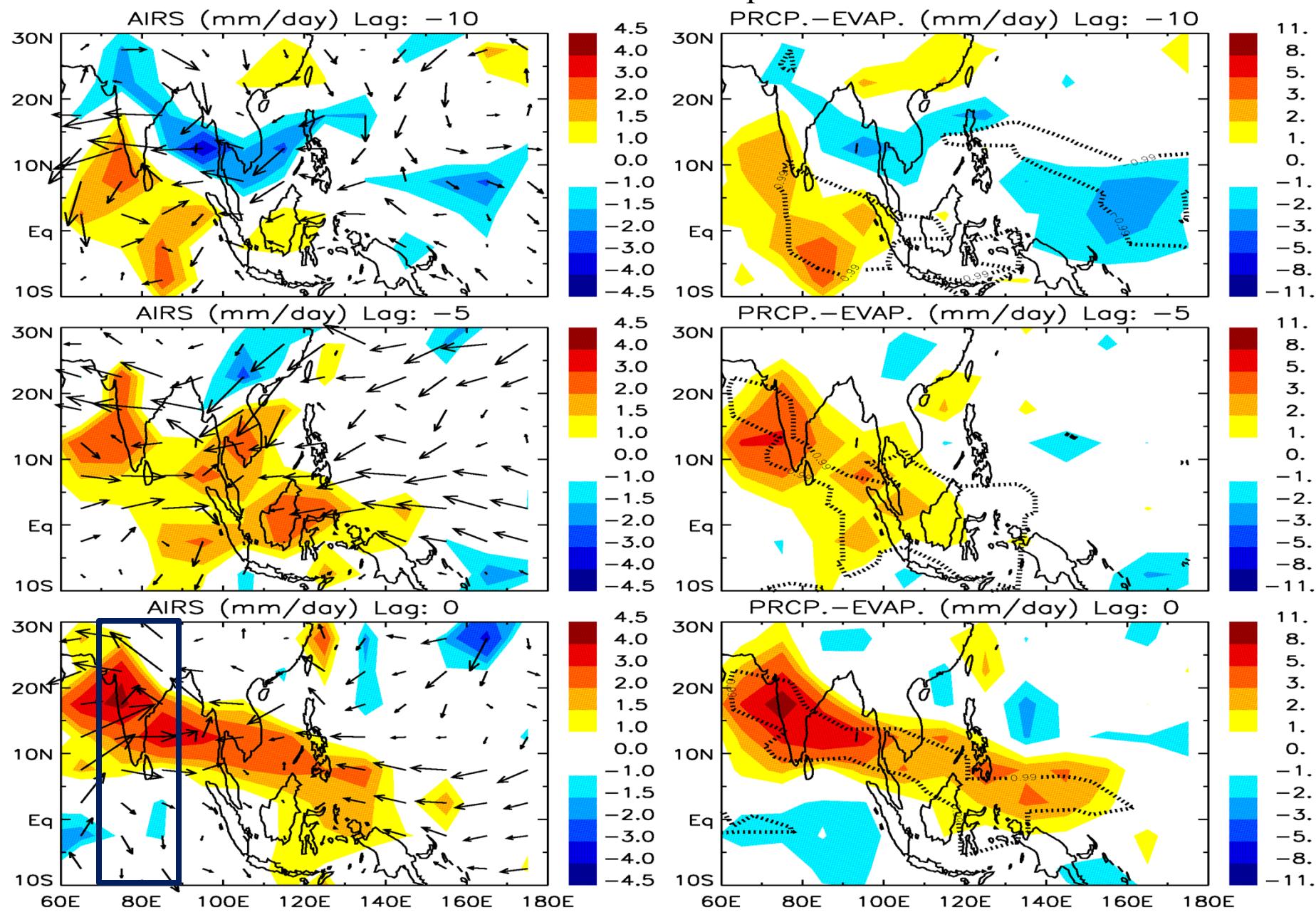
$-\int \mathbf{S} \cdot d\mathbf{p}/g$  from AIRS q<sub>v</sub> and MERRA winds

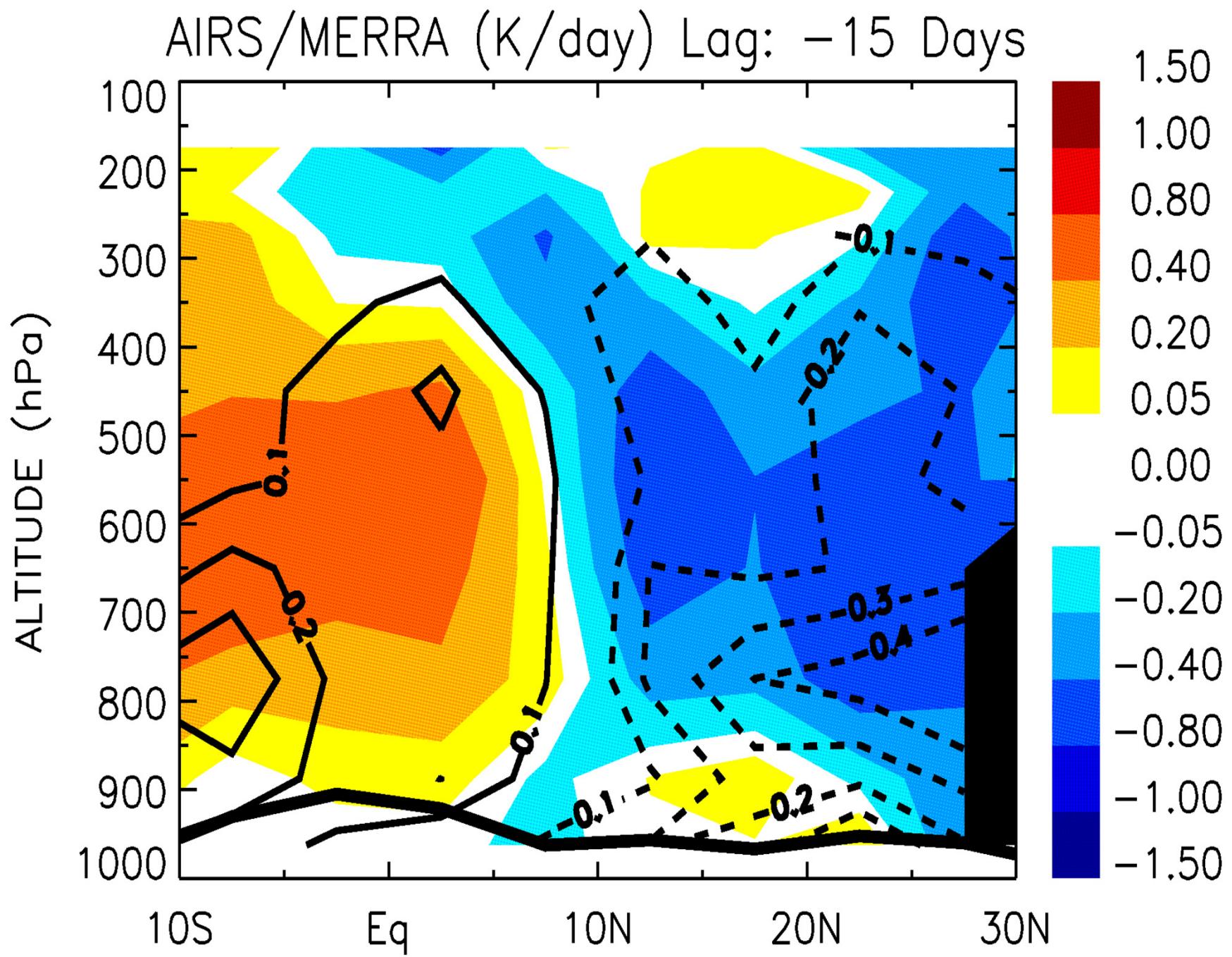


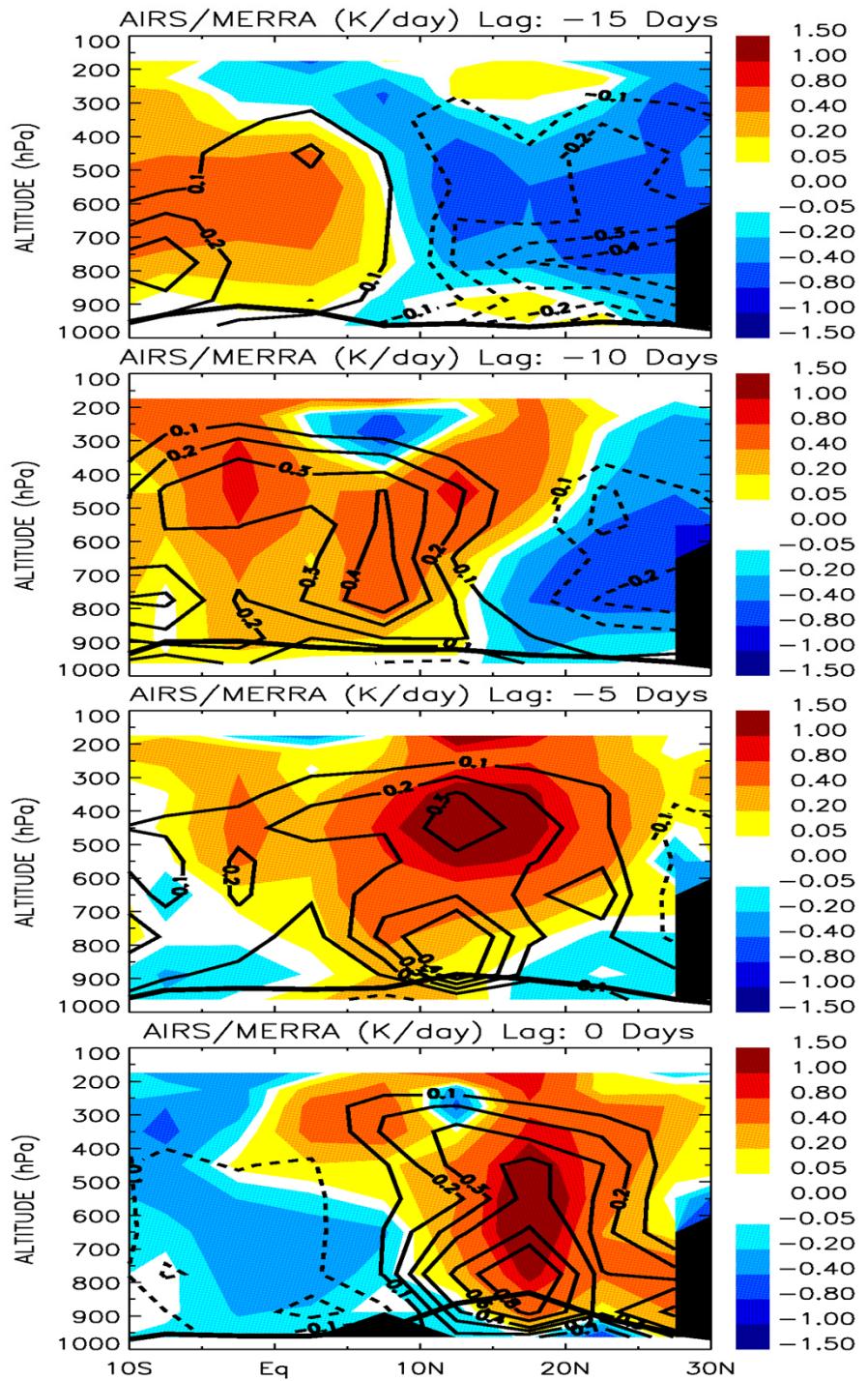
$\int S \cdot dp/g$  from AIRS  $q$  and MERRA winds

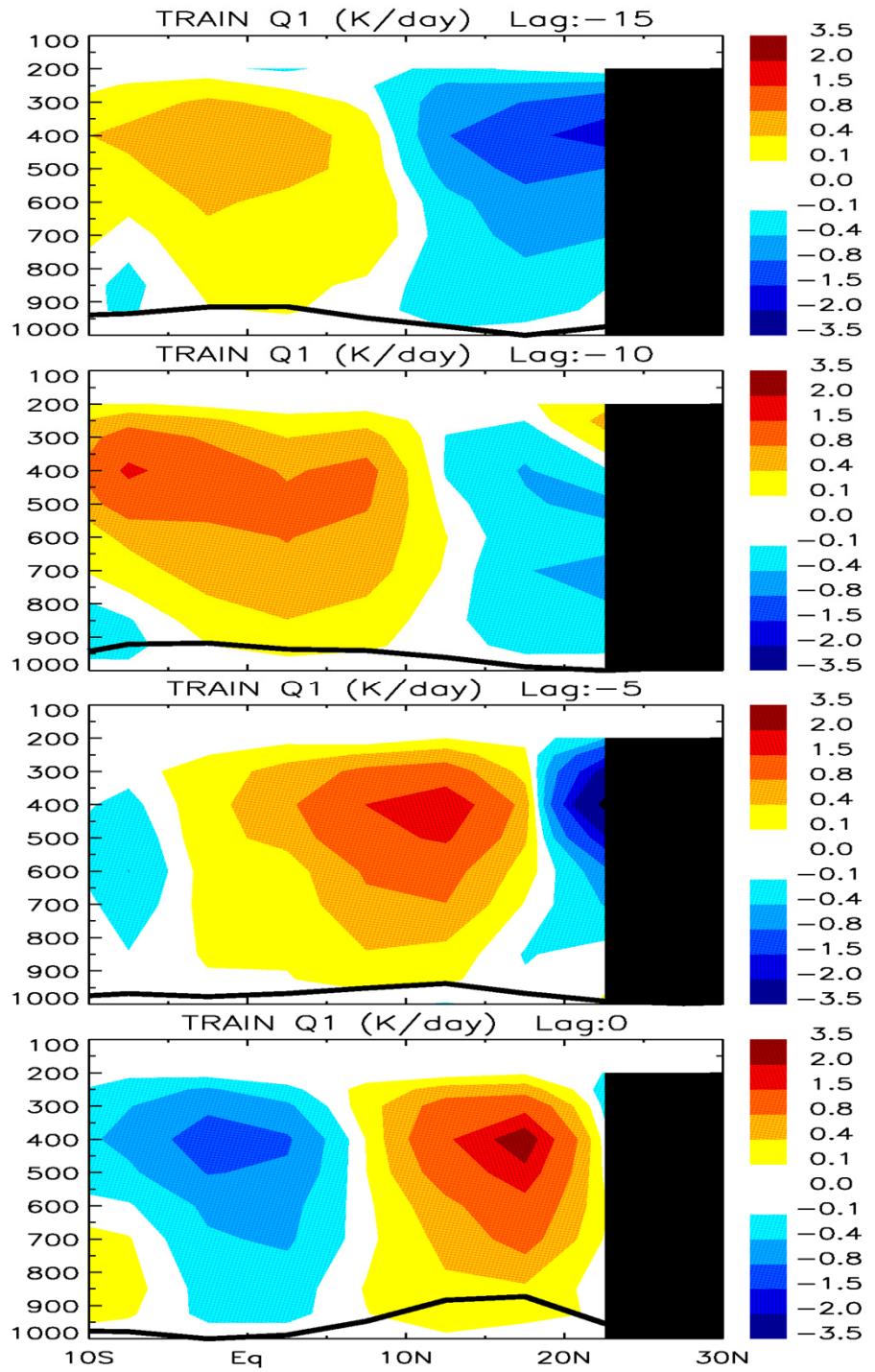
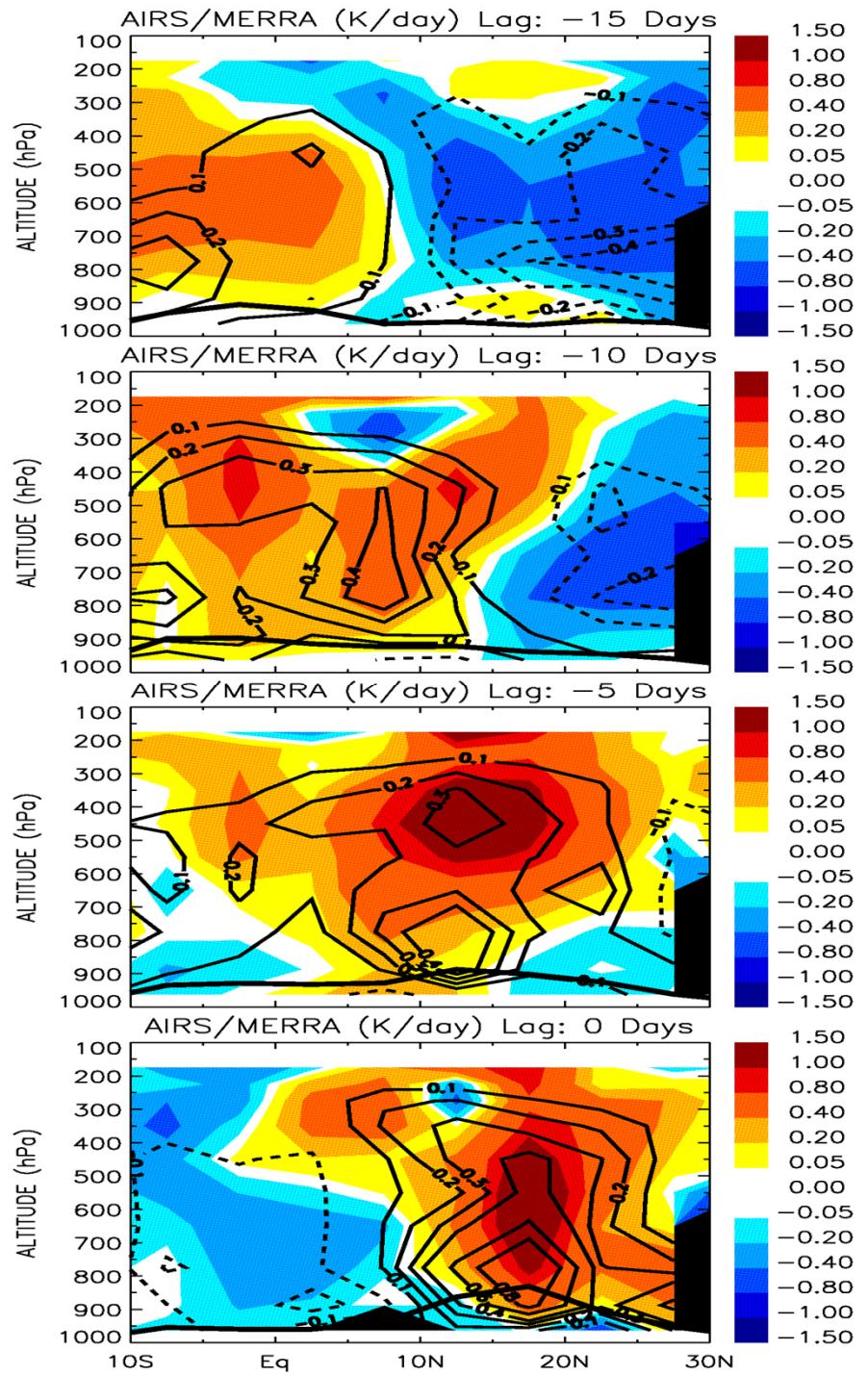


## TRMM 3b42 Precipitation – OAFlux Surface Evaporation









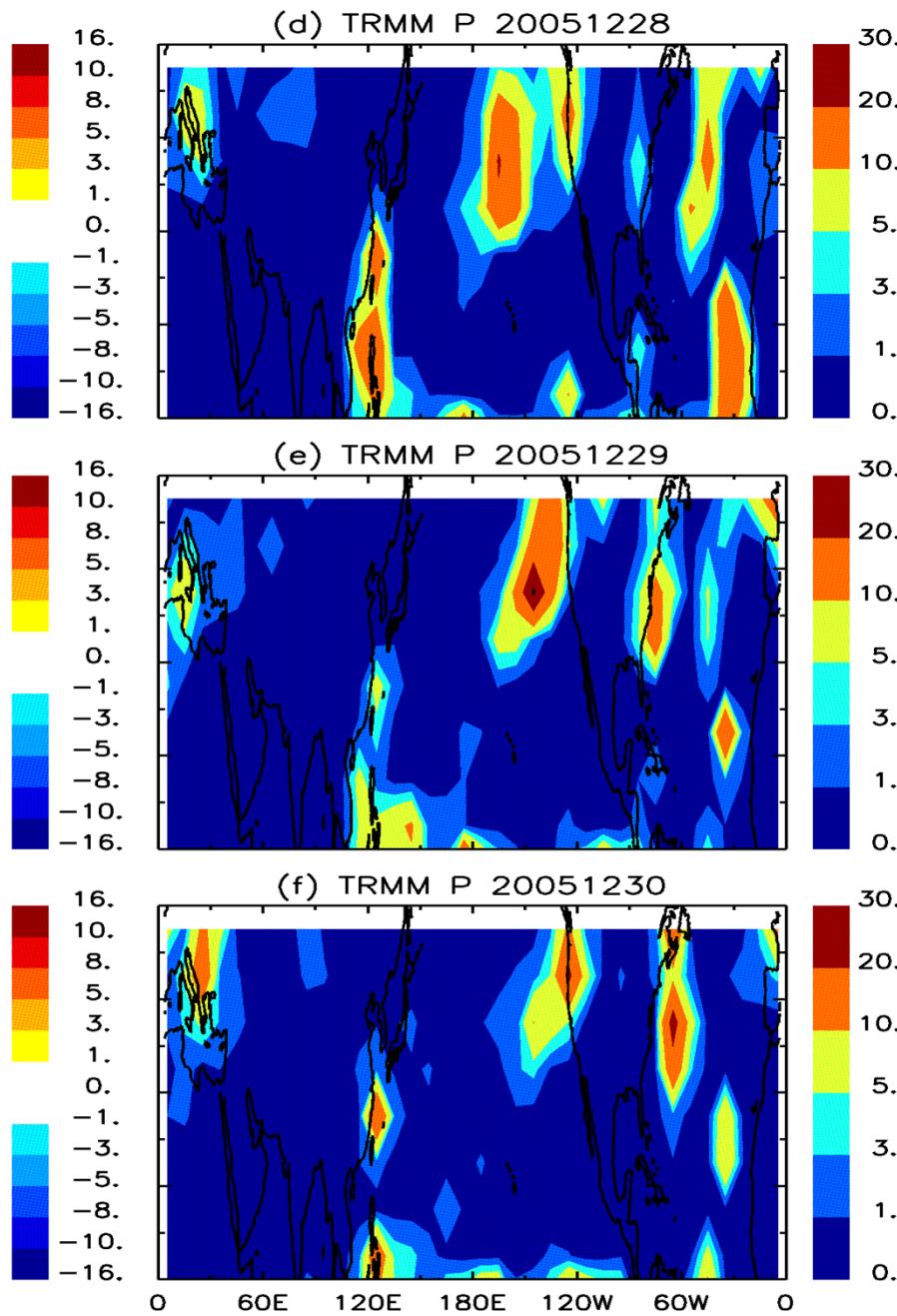
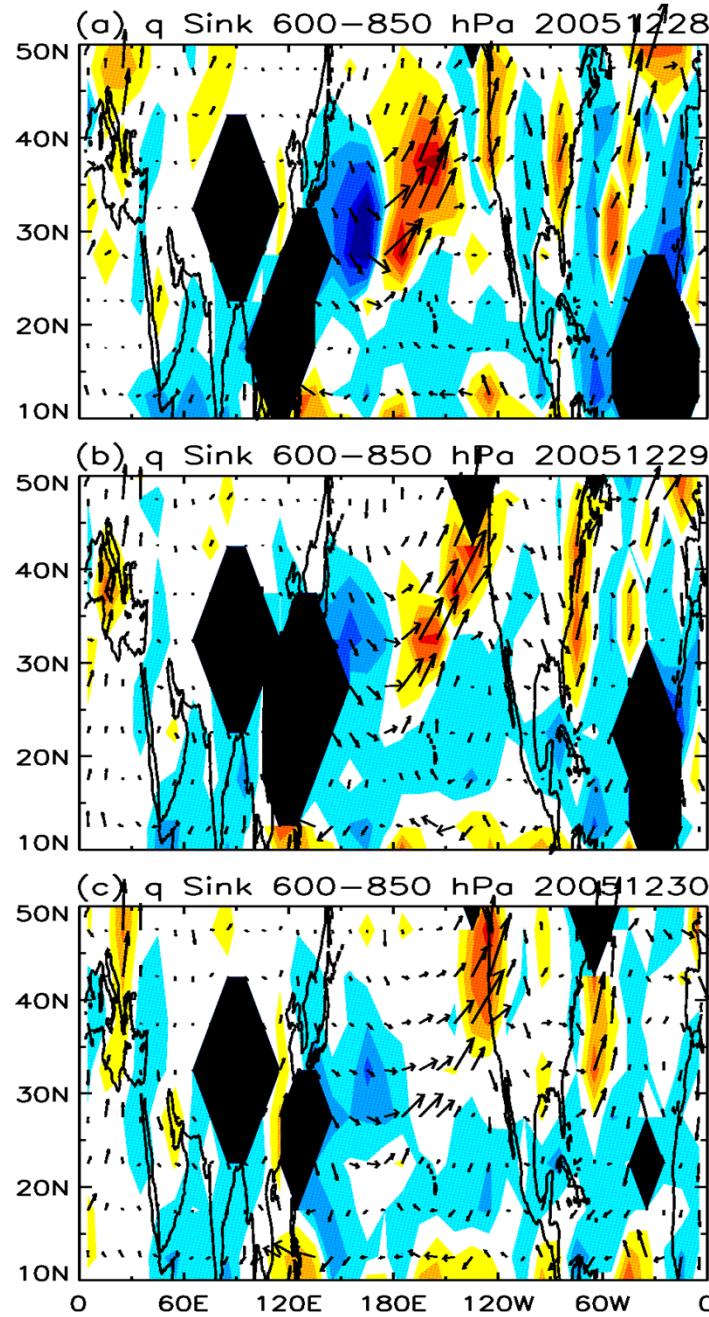
## Conclusions:

- AIRS q combined with the MERRA or ECMWF winds reproduces reasonable climatologies of P–E, compared to TRMM 3B42, GPCP, and GSSTF2b
- agreeable pattern of wavelet spectra over the ITCZ, maritime continents, and Indian continent, but underestimates the intraseasonal time-scale variability
- agreeable rainfall anomaly patterns associated with the ISO of the Indian monsoon, but underestimates (~50%) the rainfall variability and the heating anomalies

## **On-Going or Future Work:**

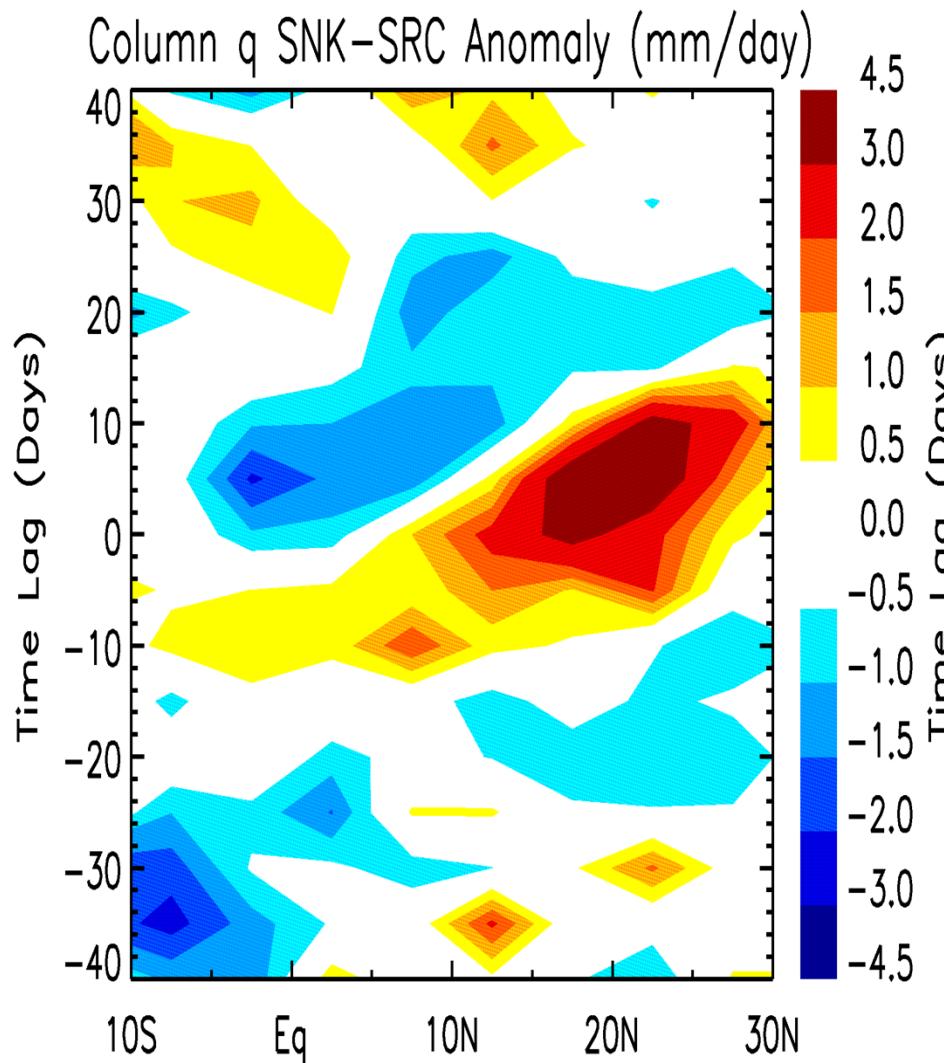
- Validation the AIRS/MERRA heating sources with TRAIN Q1 on climatologies and all time-scale variability (Bill Olson and Tristan L'Ecuyer)
- Water vapor sinks and heat sources associated with the Atmospheric Rivers (Ju-Mee Ryoo)
- Understanding the effect of clouds on biases of the q sinks and heat sources (Eric Fetzer)

# Sneak Peek on Atmospheric River

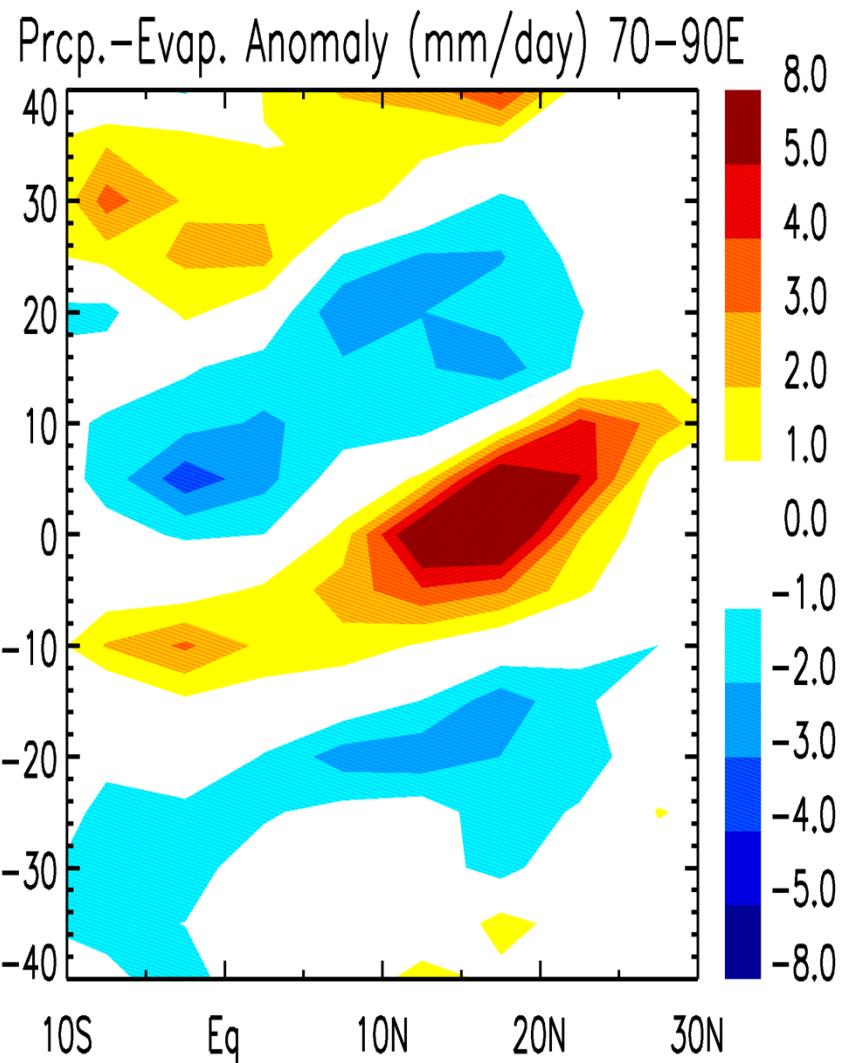


# FFT Filter of Indian Precipitation 30-100 days Hovmöller Diagram of Time Lag Composite of Anomalies

$-\int S \cdot dp/g$  from AIRS q and MERRA winds

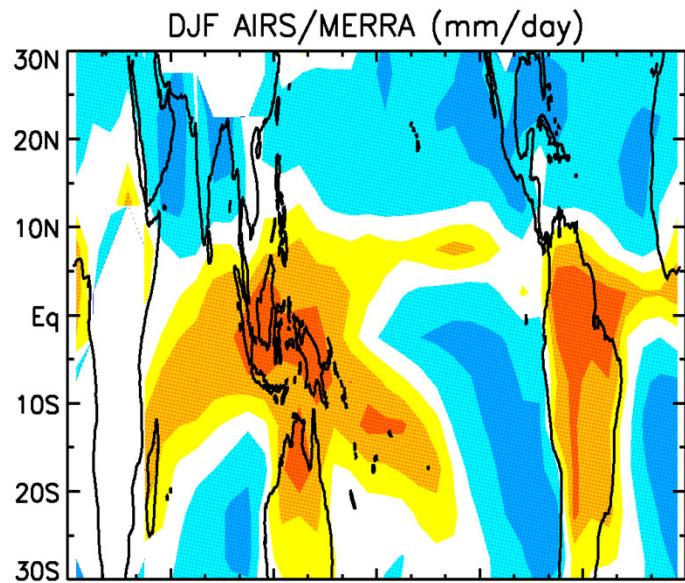


TRMM 3b42 Precipitation –  
OAFlux Surface Evaporation

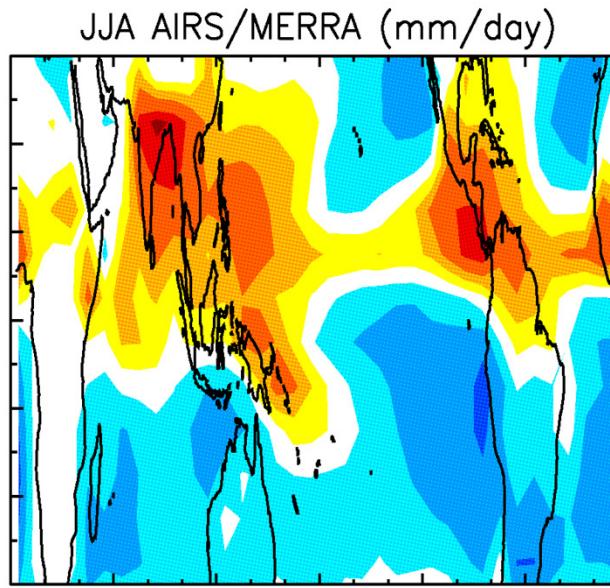


# Comparison of $\int Qdp/g$ (On-going Research)

Winter 2004-2008



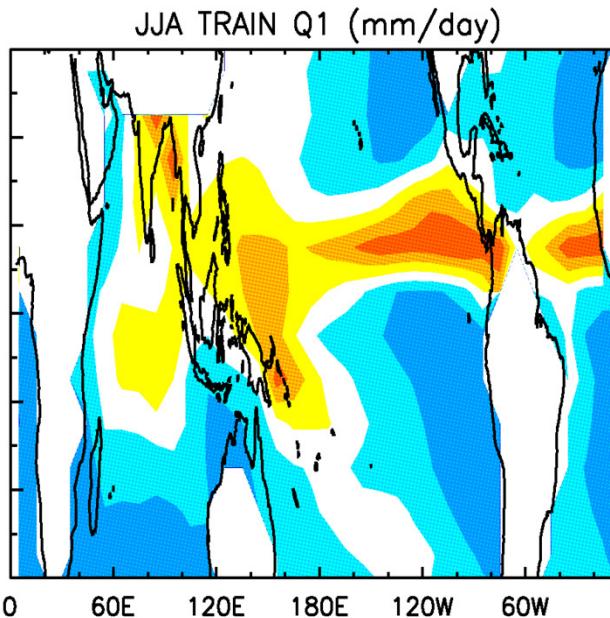
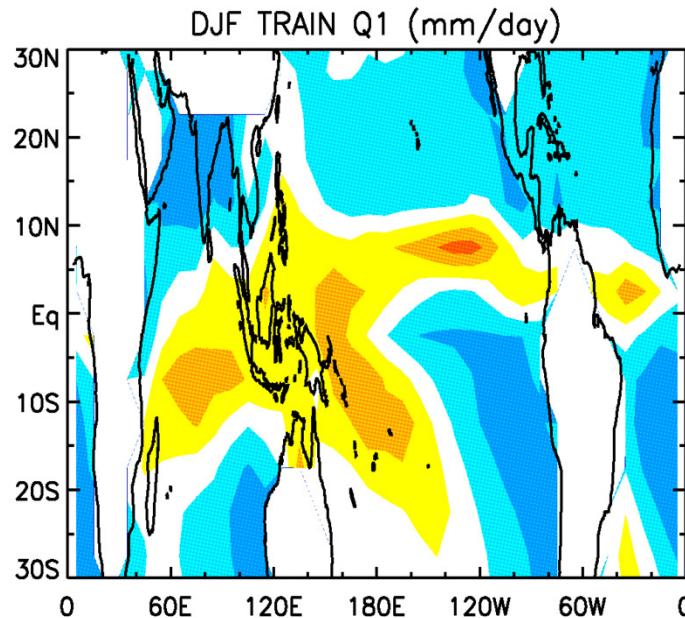
Summer 2004-2008



$\int Qdp/g / L$

AIRS T

MERRA winds



$\int Q1 dp/g / L$

Q1: TRAIN Q1

# Comparison of $\int Sdp/g$ between AIRS/MERRA and purely MERRA

